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Aircraft Icing Weather Data Reporting and Dissemination System

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Abstract

The long-term operational concept of this research is to develop an onboard aircraft system that assesses and reports atmospheric icing conditions automatically and in a timely manner in order to improve aviation safety and the efficiency of aircraft operations via improved real-time and forecast weather products. The idea is to use current measurement capabilities on aircraft equipped with icing sensors and in-flight data communication technologies as a reporting source. Without requiring expensive avionics upgrades, aircraft data must be processed and available for downlink. Ideally, the data from multiple aircraft can then be integrated (along with other real-time and modeled data) on the ground such that aviation-centered icing hazard metrics for volumes of airspace can be assessed. As the effect of icing on different aircraft types can vary, the information should be displayed in meaningful ways such that multiple types of users can understand the information. That is, information must be presented in a manner to allow users to understand the icing conditions with respect to individual concerns and aircraft capabilities.

This research provides progress toward this operational concept by:

- Identifying an aircraft platform capable of digitally capturing, processing and downlinking icing data,
- Identifying the required in situ icing data processing,
- Investigating the requirements for routing the icing data for use by weather products,
- Developing an icing case study in order to gain insight into major air carrier needs,
- Developing and prototyping icing display concepts based on the National Center for Atmospheric Research's existing diagnostic and forecast experimental icing products, and
- Conducting a usability study for the prototyped icing display concepts.

Acronyms and Abbreviations

A	Airbus
AO1	Automated station without precipitation discriminator
AO2	Automated station with precipitation discriminator
ABQ	Albuquerque
A/C	Aircraft
AC90	Rockwell 690 Turbo Commander
ACARS	Aircraft Communications Addressing and Reporting System
ACCUM	Accumulation
ACCUMN	Accumulation
ACFT	Aircraft
ACID	Aircraft identifier
ACMF	Aircraft Condition Monitoring Function
ACSL	Altocumulus standing lenticular cloud
ACT	Activity
ACTL	Actual
ACRS	Across
AD	Airworthiness Directive
ADDS	Aviation Digital Data Service
ADF	Airline Dispatchers Federation
ADJ	Adjacent
ADNL	Additional
AFD	Airport/Facility Directory
AFTN	Afternoon
AGL	Above ground level
ALG	Along
ALS	Approach Light Systems
ALT	Altitude
ALTMR	Altimeter
ALTN	Alternate
AIRMET	Airman's Meteorological Information
ALG	Along
AMDT	Amendment
AMS	Air mass
ARINC	Aeronautical Radio, Inc.
ARVL	Arrival
ASA	Aviation Supplies & Academics
ASSOCD	Associated
ATC	Air traffic control
ATIS	Automatic Terminal Information System
ATL	Atlanta
AVG	Average
AWABS	Aircraft Weight and Balance (and Takeoff Performance) Data
AWC	Aviation Weather Center

AWIN	Aviation Weather Information
AZ	Arizona
AZM	Azimuth
B	Began Also Boeing
B190	Beech 1900 Airliner
BE	Beech
BE19	Beech B-19 Musketeer
BE20	Beech 200 Super King Air, C-12 A to F
BE55	Beech E-55 Baron
BFG	BFGoodrich
BKN	Broken
BL	Blowing
BLO	Below
BLW	Below
BR	Mist (visibility 5/8-6 SM)
BRF	Brief
BTN	Between
BTR	Better
BTWN	Between
BYD	Beyond
C	Celsius Also Cessna
C177	Cessna 177, Cardinal
C206	Cessna 206 series
C550	Cessna 550/552 Citation 2
CA	California
CARJ	Canadair Regional Jet
CAS	Calibrated airspeed
CAT	Category Also clear air turbulence
CAVOK	Ceiling and visibility OK
CB	Cumulonimbus
CDFNT	Cold front
CDL	Configuration Deviation List
CHG	Change
CI	Cost index
CIG	Ceiling
CLB	Climb
CLD	Cloud Also cold
CLDS	Clouds
CLR	Clear
CLSD	Closed
cm	Centimeter
CNTNGNCY	Contingency
CNVTN	Convection
CO	Colorado

	Also company
CONDS	Conditions
CONT	Continuous Also Continue
CONTG	Continuing
CONUS	Continental United States
COORD	Coordinates
COR	Correction (to a previously disseminated report)
COS	Colorado Springs Also because
CPR	Casper
CR	Carriage return
CRZ	Cruise
CSTL	Coastal
CTR	Center
CTRLINE	Center line
CVG	Cincinnati
CYS	Cheyenne
CZ	Cruise
D328	Fairchild Dornier 328
DAL	Delta Air Lines
DCT	Direct
DEN	Denver
DEP	Departure
DEPT	Departure
DEST	Destination
DH	Decision Height
DIR	Direction
DLAS	Delays
DME	Distance measuring equipment
DOM	Domestic
DRZL	Drizzle
DS	Dust storm
DSNT	Descent Also Distant
DU	Dust
DURC	During climb
DURD	During descent
DURGC	During climb
DURGD	During descent
DVER	Database version
DVLPG	Developing
DZ	Drizzle
E	East Also ended
ECN	Economy
ECON	Economy flight plan based on minimum cost for FMS equipped aircraft
EEC	Engine Electronic Control
Eff	Effective
ELEV	Elevation
EMBDD	Embedded

ENRTE	En route
ER	Extended range
ERN	Eastern
ETA	Estimated time of arrival
ETE	Estimated time en route
EWD	Eastward
EXP	Expected
EXPD	Expected
F2TH	Falcon 2000
FA	Area forecast Also final approach Also flight attendant
FAA	Federal Aviation Administration
FAP	Final approach
FAR	Federal Aviation Regulation
FC	Funnel cloud
FDC	Flight Data Center
FG	Fog (visibility < 5/8 SM)
FL	Flight level Also Florida
FLT	Flight
FM	From Also flight mode
FMS	Flight Management System
FOB	Fuel on board
FOD	Foreign object debris
FOM	Flight Operations Manual
FP	Flight plan
FRMG	Fuel remaining to destination
FT	Feet
FU	Smoke
G	Gusts
GLF4	G-1159C Gulfstream 4
FZ	Freezing
GA	Georgia
GJT	Grand Junction
GMT	Greenwich Mean Time
GOES	Global Orbiting Earth Satellite
GPS	Global Positioning System
GR	Hail >= ¼ inch
GRD	Ground
GRTR	Greater
GS	Ground speed Also small hail
GST	Gust
HAT	Height Above Touchdown
HF	High Frequency
HVY	Heavy
HZ	Haze
IAF	Initial approach fix
IAS	Indicated airspeed
IC	Icing Also ice crystals Also in-cloud lightning

ICAO	International Civil Aviation Organization
ICGICIP	Icing in clouds and in precipitation
ICGIP	Icing in precipitation
ID	Identifier
IFR	Instrument flight rules
IIDA	Integrated Icing Diagnostic Algorithm
IIFA	Integrated Icing Forecast Algorithm
ILS	Instrument Landing System
IMC	Instrument meteorological conditions
IN	Inch
INCLDS	Includes
INCR	Increasing
INOP	Inoperative
INT	Intersection
INTX	Intersection
INTL	International
JTSTR	Jet stream
K	Kilo
KIAS	Knots indicated airspeed
KM	Kilometer
KT	Knots
L	Left Also local time Also TCAS-equipped B757
LAT	Latitude
Lb	Pound
LF	Line feed
LGT	Light
LGTS	Lights
LJ35	Learjet 35/36
LMT	Limit
LN	Line
LNDG	Landing
LOC	Localizer
LON	Longitude
Long	Longitude
LT	Light
LVL	Level
LWC	Liquid water content
LWR	Lower
LWT	Planned landing weight
M	Minus Also Mach Also million
mA	milliampere
MAX	Maximum
MCH	Mach
MD	McDonnell Douglas
MDA	Minimum Descent Altitude
MDCRS	Meteorological Data Commercial Reporting System
MDT	Moderate
MEA	Minimum En route Altitude

MEL	Minimum Equipment List
MEM	Memphis
METAR	Aviation Routine Weather Report
M/H	Magnetic heading
MI	Mile
MIN	Minimum
MNLY	Mainly
MOD	Moderate
MOGR	Moderate or greater
MOPS	Minimum Operational Performance Standards
MOV	Moving Also movement
MOVG	Moving
MPTW	Maximum planned take off weight
MS	Mail stop
MSL	Mean sea level
MT	Mountain
MTN	Mountain
MXD	Mixed
NASA	National Aeronautics and Space Administration
NAV	Navigation
NC	North Carolina
NCAR	National Center for Atmospheric Research
N	North
NBR	Number
NDB	Non-directional beacon
NEG	Negligible
NM	Nautical miles
NMI	Nautical miles
NMRS	Numerous
NOAA	National Oceanic and Atmospheric Administration
NOSPECI	No SPECI reports are taken at the station
NOTAM	Notice to Airmen
NRP	National Route Program
NTSB	National Transportation Safety Board
NV	Nevada
NWP	Numerical weather prediction
NWS	National Weather Service
NXT	Next
OCLN	Occlusion
OCNL	Occasional
OCR	Occur
OFFSHR	Offshore
OG	On ground
OKC	Oklahoma City
OLCP	Occasional light chop
OM	Outer Marker
OMTNS	Over mountains
OR	Oregon

OTS	Out of service
OV	Over
OVC	Overcast
OVR	Over
P	Precipitation Also plus
PA31	Embraer 820
PAY1	PA-31T1-500 Cheyenne 1
PD	Period
PE	Ice pellets
PG	Page
PK	Peak
PIREP	Pilot report
PLND	Planned
POS	Position
PR	Partial
PREF	Preferred
PRESS	Pressure
PRESRR	Pressure rising rapidly
PSBL	Possible
PUB	Pueblo Also published
PWR	Target power setting
PY	Spray
R	Reporting point (to company) Also right
RA	Rain
RAOB	Radiosonde observation
RCMND	Recommend
RCV	Receive
RLS	Release
RM	Remark
RMK	Remark
RMN	Remain
RPT	Report
RPTD	Reported
RTE	Route
RUC	Rapid update cycle
RVR	Runway Visual Range
RWY	Runway
S	South
SAT	Static air temperature
SC	South Carolina Also South Central
SCAT	Scattered
SCT	Scattered
SE	South East
sec	Second
SEV	Severe
SFC	Surface
SG	Snow grains
SH	Showers
SIGMET	Significant Meteorological Information

SKC	Sky clear
SKED	Schedule
SLC	Salt Lake City
SLD	Supercooled Liquid Droplet
SLP	Sea level pressure
SLPG	Sloping
SM	Statute mile
SMTH	Smooth
SN	Snow
SPD	Speed
SPECI	Special
SQ	Squall
SS	Sand storm
STG	Strong
STN	Station
SW	Southwest
T	Temperature
TA	Temperature
TACAN	Tactical Air Navigation
TAF	Aerodrome Forecast
TAS	True airspeed
TAT	Total air temperature °C
TB	Turbulence
TBD	To be determined
TC	True course
TCU	Towering cumulus
TEM	Temperature deviation from standard
TEMP	Temperature Also temporary
TEMPO	Occasionally
THLD	Threshold
TIND	Turbulence Indicator
TM	Time
TMP	Temperature
T/O	T/O
TOC	Top of climb
TOD	Top of descent
TP	Type
TRB	Turbulence
TRFC	Traffic
TRG	Trigger
TRMG	Time remaining to destination
TROF	Trough
TROP	Tropopause altitude
TRW	Thunderstorm
TS	Thunderstorm
TSHWR	Thunder shower
TSTM	Thunderstorm
TUL	Tulsa
TURB	Turbulence
TURBC	Turbulence
TWR	Tower
UA	Pilot report
UKN	Unknown

UNKN	Unknown
UNUSBL	Unusable
UP	Automated observation
UPDT	Update
UPSLP	Up slope
UT	Utah
UTC	Coordinated Universal Time
V	Variable
VA	Volcanic ash
Var	Variation
VC	Vicinity
VFR	Visual Flight Rules
VHF	Very High Frequency
VIS	Visibility
VOR	Very High Frequency Omni-directional Range
VRBL	Variable
VV	Vertical visibility (into a total obscuration listed in hundreds of feet AGL)
W	West
WA	AIRMET Also Washington
WCP	Average wind component (M = headwind; P = tailwind)
WD	Wind direction
WDLY	Widely
WND	Wind
WNDSHR	Wind shear
WS	Wind shear Also wind speed
WST	Convective Significant Meteorological Information
WT	Weight
WTRS	Waters
WV	Wave Also wind vector
Wx	Weather
WY	Wyoming
XPCT	Expect
Z	Zulu time
ZD	Zone distance
ZDV	Denver Air Route Traffic Control Center
ZF	Zone fuel
ZT	Zone time; Coordinated Universal Time

Introduction

Types and Severity of Icing

Accretion of ice on aircraft surfaces in flight is a result of cloud droplets remaining in a liquid state at temperatures below freezing. The severity of icing (categorized in terms of trace, light, moderate and severe [ASA, 1999]) is generally dependent upon the accretion rate. The amount, type and shape of ice accreted is dependent on several variables (Jeck, 1996; Pobanz, Marwitz & Politovich, 1994; Politovich, 1989; Ryerson, 2000) such as:

- Aircraft airspeed (e.g., increased airspeed means the droplets have less time to flow around an object and the surface of the airfoil is heated by friction),
- Aircraft type (e.g., size and shape of objects affect collection efficiency and accumulation),
- Cloud phase (supercooled liquid water freezes on aircraft structures while ice crystals do not),
- Droplet size (droplet size affects collection rates, ice shape and type, and runback),
- Duration in the icing (given more time, more ice can form),
- Liquid water content (LWC) (icing occurs at particular LWC depending on factors such as cloud type and altitude),
- Temperature (temperature affects the type and location of ice on the airframe; the rate of ice accumulation is directly related to LWC for a given temperature), and
- Wind shear (disturbances can cause icing to initiate).

Of all these variables, the more diagnostic ones are currently least accessible. LWC is probably the most important in determining the severity of the icing conditions (Politovich, 1989). Unfortunately, without access to the output of specialized sensors aboard aircraft flying through the area, it is difficult to determine LWC. Another major factor in icing accretion is droplet size. However, individual droplets capable of producing structural ice are too small to be seen through a cockpit window. Droplet size is also difficult to determine with the instrumentation currently installed on aircraft.

Problems Associated with Icing

Problems associated with icing can be grouped into two main categories: 1.) safety and accident rates and 2.) increased operating cost.

Safety and Accident Rates

Icing remains one of aviation's leading hazards (c.f., Boeing, 2001; NASA, 1998; NTSB, 1996, 1998). Weather conditions are never totally predictable and icing forecasts are not provided with the temporal and spatial accuracy and timeliness to help pilots avoid hazardous icing encounters.

The effects of icing on an aircraft are aircraft specific and have been found to affect various aircraft components and systems including:

- Modification of the airflow pattern, leading to loss of lift or an increase in drag,
- Loss in engine power,

- Loss in propeller efficiency,
- Increase in weight,
- Unbalancing of the control surfaces,
- Errors in the instruments if the pitot tube or static vent are blocked,
- Degradation of radio communication, and
- Degradation of visibility through the windshield.

All aircraft are susceptible to icing — even those with anti-icing equipment. Most aircraft involved in icing accidents are general aviation type aircraft, but there is a significant number of larger, commercial aircraft that have been involved in icing accidents (c.f., Aviation Safety Network, 1998; Boeing, 2001; NASA, 1998). Apparently, experienced pilots are not taking corrective action when icing conditions are encountered. This may suggest a lack of understanding of the seriousness of an icing encounter on the performance of the aircraft and/or a lack of understanding of the weather factors contributing to icing conditions. It may also suggest that pilots are unable to visually detect the ice accretion until aircraft performance noticeably degrades. These pilots most likely lacked adequate awareness of the nature and severity of the icing problem.

Complicating the icing safety issue is that both structural and engine icing must be considered. For example, an aircraft with an inoperative wing anti-ice valve must consider the potential for "hard ice" while one with an inoperative engine anti-ice valve must consider "soft ice" (Myszkowski & Rezsonya, 1996). "Hard" ice occurs between 0 and -40° C in visible moisture, and where "soft" ice (ice that can form once air is cooled) can occur if the temperature is between 10 and -20°C and when the humidity is high. Thus, the corrective action varies depending on the type of operative equipment.

Several factors suggest that the potential for hazardous icing encounters will continue. Aircraft designs continue to include features that make aircraft susceptible to icing such as laminar flow airfoils and efficient engines intolerant of contamination (Ryerson, 2000). As air traffic increases and new air traffic route structures are created, aircraft may be increasingly exposed to icing conditions. For example, the use of lower en route cruise altitudes, necessary to accommodate the increase in air traffic, may expose aircraft to icing conditions for longer periods than previous higher altitude routings did (RTCA, 1995).

Increased Operating Costs

Compensating for areas of anticipated or encountered icing yields disruptions in planned altitudes and/or routing, significantly decreasing aircraft efficiency and therefore increasing operating costs. Three areas in which icing significantly increases operating costs are:

1. *Remaining at an altitude or on a course for too long, given the icing conditions*: Because pilots may not have timely forecasts or may be relying on the inadequate subjective assessments of other pilots of icing conditions enroute, some may "ride out" an icing encounter for too long. This could be both dangerous and costly in terms of fuel reserves. However, if these pilots were to make a more timely decision to avoid the area of icing (based on more precise icing information), resources would be used more effectively. Typically, though, most pilots aggressively seek to avoid icing encounters believed to be beyond the capability of the aircraft.
2. *Prematurely vacating an optimum altitude or course based on reports of icing ahead*: Once a flight receives reports of or encounters unexpected icing, a pilot (with the help of a flight dispatcher for airline operations) must assess the current severity, solicit additional route and

altitude information regarding icing from air traffic control (ATC), and calculate fuel reserves and time constraints to determine the best course of action. Because reports of icing are subjective, based on the type of aircraft and the experience and priorities of the crew making the report, the variability of the reports is considerable. Pilots have little or no objective data on which to base a decision. They often err on the conservative side and request a change in altitude or course.

3. *Avoiding areas of forecasted icing that actually would not adversely affect the flight*: Forecasting icing is difficult. Further complicating this situation is that different aircraft experience the same icing conditions differently. What may be "moderate" for one aircraft type may only be "light" for another aircraft. Reports and forecasts should account for the specifics of the particular aircraft type, but this information may not always be available. Despite oftentimes inaccurate forecasts, it is the responsibility of the Pilot-in-Command (and Flight Dispatcher for airline operations) to assess the planned route of flight and make adjustments as necessary in an attempt to avoid "significant" icing. In some cases, flights are delayed or are cancelled altogether. In other cases, these adjustments mean flying several thousand feet above or below the optimum altitude, or they may require flying a circuitous route around the area of forecast icing. These preflight planning adjustments may require increased fuel loads and/or longer flight times. These adjustments are expensive because they either add to the operating costs or lower the revenues.

Problems Associated with the Current Icing Reporting System

As previously discussed, there are significant costs associated with icing encounters. Many of these problems are exacerbated by the sporadic, subjective, and imprecise way in which icing is currently measured and reported (ASA, 1999; Kelsch & Wharton, 1996). Many aircraft are not instrumented to provide the pilot with any more data than is visually detectable through a cockpit window. The current reporting system suffers from several shortcomings that are discussed next.

Pilot assessment is subjective

Currently, icing is categorized and reported using a subjective system that requires the crew to assess the type of ice being accumulated, and then determine the aircraft's reaction to it in terms of performance. The type and amount of ice are left to the "eyes of the beholder." Each pilot makes his own judgment about the severity of weather events. New and low time pilots are known to overestimate the intensity of icing (Lankford, 1995). Additionally, current approved report terminology is too subjective to provide accurate descriptions of icing conditions. A related problem is that pilots are trained to report ice in terms of observable phenomena that are not perfectly diagnostic (Lankford, 2000) (Table 1 and Table 2). Ice types are more a function of ice accretion shape, rather than color or opacity, yet pilots are not trained accordingly.

Table 1. Types of icing

Rime ice	Rough, milky, opaque ice formed by the instantaneous freezing of small supercooled water droplets. This generally occurs in stratiform clouds at temperatures between 0 and -20°C.
Clear ice	A glossy, clear or translucent ice formed by the relatively slow freezing of large supercooled water droplets. This generally occurs in cumulus clouds or freezing precipitation between 0 and -40°C.
Mixed ice	A combination of rime and clear ice.

Table 2. Intensity of icing and required actions

Category	Description	Required action
Trace	Ice becomes perceptible. Rate of accumulation is slightly greater than the rate of sublimation.	De/anti-icing equipment is not utilized unless encountered for an extended period of time (over 1 hour).
Light	The rate of accumulation may create a problem if the flight is over one hour in this environment.	Use of de/anti-icing equipment removes/prevents accumulation. Without icing prevention equipment, one should consider a change of course or a 180° turn.
Moderate	The rate of accumulation is such that even short encounters become potentially hazardous.	Use of de/anti-icing equipment or flight diversion is necessary. Light single and twin airplanes may not be able to climb through this type of icing.
Severe	The rate of accumulation is such that the de/anti-icing equipment fails to reduce or control the hazard.	Use de/anti-icing equipment. Immediate flight diversion is necessary.

Forecasts and reports are not aircraft-specific

Different types of aircraft have different sensitivities to icing. Leading edge radius of curvature, wing surface area, wing sweep angle, and typical operating altitudes and airspeeds affect in-flight icing accumulation. Thus, a report of "moderate" icing by one aircraft may not be reported by another flying through the same area.

Reports are given voluntarily and are not generally available

Pilots are urged to volunteer reports of icing conditions. Federal Aviation Administration (FAA) air traffic facilities are required to solicit reports under certain conditions (ASA, 1999). However, the lack of PIREP availability is well known. PIREP availability is determined by factors such as pilot and controller attention and workload. PIREPs, when given, are not evenly distributed in either time or space (Kelsch & Wharton, 1996; Schwartz, 1996). In addition, there are very few PIREPs that report good conditions (Schwartz, 1996). Exacerbating the problem is that, even when PIREPs are made, they are not available to all airspace users. Icing conditions reported to busy air traffic controllers may only be passed along verbally to other pilots in the sector and may be delayed (Hansman & Wanke, 1989). Also, unless entered by someone, the data is lost.

Reports may be given to the company verbally or electronically but are not routinely available to others. Many U.S. carriers have aircraft equipped to downlink icing reports via the Aircraft Communications Addressing and Recording System (ACARS), a line-of-sight VHF telecommunication system. This data is maintained at each company and is not always shared. In order to facilitate the sharing of this information, the Meteorological Data Commercial Reporting System (MDCRS) Working Group (an informal advisory group) is dealing with issues like reporting frequency, data formats, and cost reimbursement. However, there are currently few participating airlines. In addition, airlines wish to keep down communication costs and to avoid expensive changes to their aircraft. These concerns are addressed more specifically later in this report.

Aircraft participating in sharing weather data provide latitude, longitude, altitude, time, temperature, and wind direction and speed. Some report vertical acceleration (an indirect measure of turbulence), and a handful experimentally report eddy dissipation rate (an aircraft-independent measure of turbulence) (Cornman & Sharman, 1999). In the future, a few aircraft may provide experimental dewpoint data. MDCRS is considering adding icing data (i.e., a binary ice detection parameter) depending on the associated costs, some of which are addressed later in this report.

Pilots may not be able to see ice

Ice accretions that affect the stability and control of the airplane may be very small and rather unspectacular in appearance (Green, 1998). Because of some aircraft designs, pilots may not physically be able to see enough of the wing surface to make an icing determination. There are also times when ice may form in such a manner that the pilots cannot visually detect its presence. Often the autopilot masks the disturbance, so the crew is unaware of the icing until the autopilot "gives up" and hands the aircraft back to the pilot with a serious control problem (Green, 1998).

The FAA has recognized the potential hazard of aircraft icing and has written regulations concerning aircraft operation in icing conditions as well as non-regulatory guidelines. For example, Airworthiness Directives (ADs) currently limit specific turbo-prop aircraft from flight in freezing rain or freezing drizzle based on pilot-observed visual cues. These visual cues include (FAA, 1996):

- Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice,
- Accumulation of ice on the upper surface (for low wing aircraft) or lower surface (for high wing aircraft) of the wing aft of the protected area, and
- Accumulation of ice on the propeller spinner farther back than normally observed.

Even with regulations and guidelines, pilots are still experiencing roll upsets, loss of control and accidents because they cannot identify these cues. Furthermore, pilots of aircraft operating at lower altitudes are more likely to encounter icing conditions. It is difficult, then, for these pilots who operate in such conditions on a regular basis to identify frequently experienced conditions as something "unusual." New or low time pilots obviously have difficulty identifying situations as unusual. All pilots, especially those operating at lower altitudes, need more timely, objective information with regard to wing contamination and icing conditions.

In addition to visual cues on the surface of the aircraft, pilots sometimes use precipitation as a cue for icing conditions. Unfortunately though, the icing conditions typically occur in clouds that do not produce rain or snow on the ground. A particularly hazardous form of icing occurs when aircraft encounter supercooled liquid water (temperatures below $0^{o}C$) in the drizzle drop size (30-300 microns diameter) and high relative humidity (Pobanz, Marwitz & Politovich, 1994; Politovich, 1989). However, in order for these drizzle drops to form, the atmosphere must be undergoing upward vertical motion at slightly faster speeds than the large-scale lifting that forms large cloud masses (about 1 cm/sec). Too much upward vertical motion and water drops larger than drizzle-size quickly develop. The optimum vertical motion is on the order of 10 cm/sec. This condition occurs frequently at cloud tops, and is a good explanation of why significant icing is often observed there.

Weather system measurement is imprecise

The density, frequency and resolution capability of today's observation network is incompatible with the micro-scale nature of icing. Temperature, moisture, and wind data from radiosondes are taken twice a day at stations averaging hundreds of miles apart, with a vertical resolution around 2,000 feet. Thus, these radiosonde observations (RAOBs) provide a sparse sampling of the environment. Forecasting issues arise, as predictions have to span over twelve hours. The problem is made worse at times when an upper air reporting station is missing data forcing extrapolation over a "hole" in the sampling grid. Sparse data sampling requires the forecasters' computer algorithms to smooth the prediction models vertically and horizontally to achieve a computational answer in a reasonable amount of time. In addition, there are some areas that do not have the equipment necessary to forecast icing (i.e., the far North) (Ryerson, 2000).

Existing Research Efforts to Solve These Problems

Downlink of icing data

The FAA is investigating methods for acquiring icing information from aircraft. The FAA's icing sensor downlink approach is a method with an expected low implementation cost (Riley, Lindholm, Politovich, Brown, and Strapp, 1999).

Enhanced weather products

A number of aircraft icing diagnostic algorithms have been developed in the past several years (none of which currently use quantitative in situ icing measurements from commercial aircraft). These algorithms have used various inputs such as: pilot reports, meteorological models, satellites, surface observations and radar mosaics (c.f., McDonough & Bernstein, 1999). These algorithms have used the input data in a variety of ways and have met with some success. Unfortunately, algorithms based purely on models tend to overforecast icing by indicating it in locations where clouds do not exist. Algorithms based primarily on data from instruments (satellite, radar, surface observations) or pilot reports tend to be accurate in the locations where they indicate icing, but they underforecast icing because none of these instruments can identify all icing locations by themselves.

NCAR's Integrated Icing Diagnostic Algorithm (IIDA) takes advantage of the abilities and minimizes the shortcomings of both the model-based and instrument-based approaches (McDonough & Bernstein, 1999). IIDA is run every hour to create a diagnostic based on relatively recent pilot reports, satellite data, surface observations, radar mosaics, and the RUC (rapid update cycle) model. Pilot reports less than an hour old are considered. The satellite data is generally less than 45 minutes old. The surface observations are 5-10 minutes old and the radar data is also very current. The RUC model is generated every three hours to create forecasts for the next three hours and therefore its currency depends on when the model was last generated. According to Ben Bernstein at NCAR, the age of the RUC model does not have a great effect with respect to icing diagnosis.

IIDA integrates information from the GOES-8 satellite, surface observations, and the RUC model to identify the three-dimensional extent of clouds. It then uses information from these resources plus pilot reports and national radar mosaic to identify the locations and likelihood of both conventional and supercooled large drop icing across the United States and Canada. A situational approach is used which applies information from the different data sources in different ways, depending upon the physics expected to be at work at each location within the domain. This approach minimizes the impact of bad data from any one source. Images of the resultant icing and SLD fields, as well as the ingredients from which they are derived are available as output.

A representative IIDA diagnostic map of icing potential is shown in Figure 1. Denser/darker areas indicate regions of higher icing potential. Since icing is a three-dimensional phenomenon, the IIDA human-computer interface allows depiction of icing, SLD, and visible moisture in horizontal cross-sections at 3000 foot intervals. It also allows the user to view vertical cross-sections, by either selecting pre-defined routes or by defining a route (e.g., Denver to Milwaukee, Figure 2).

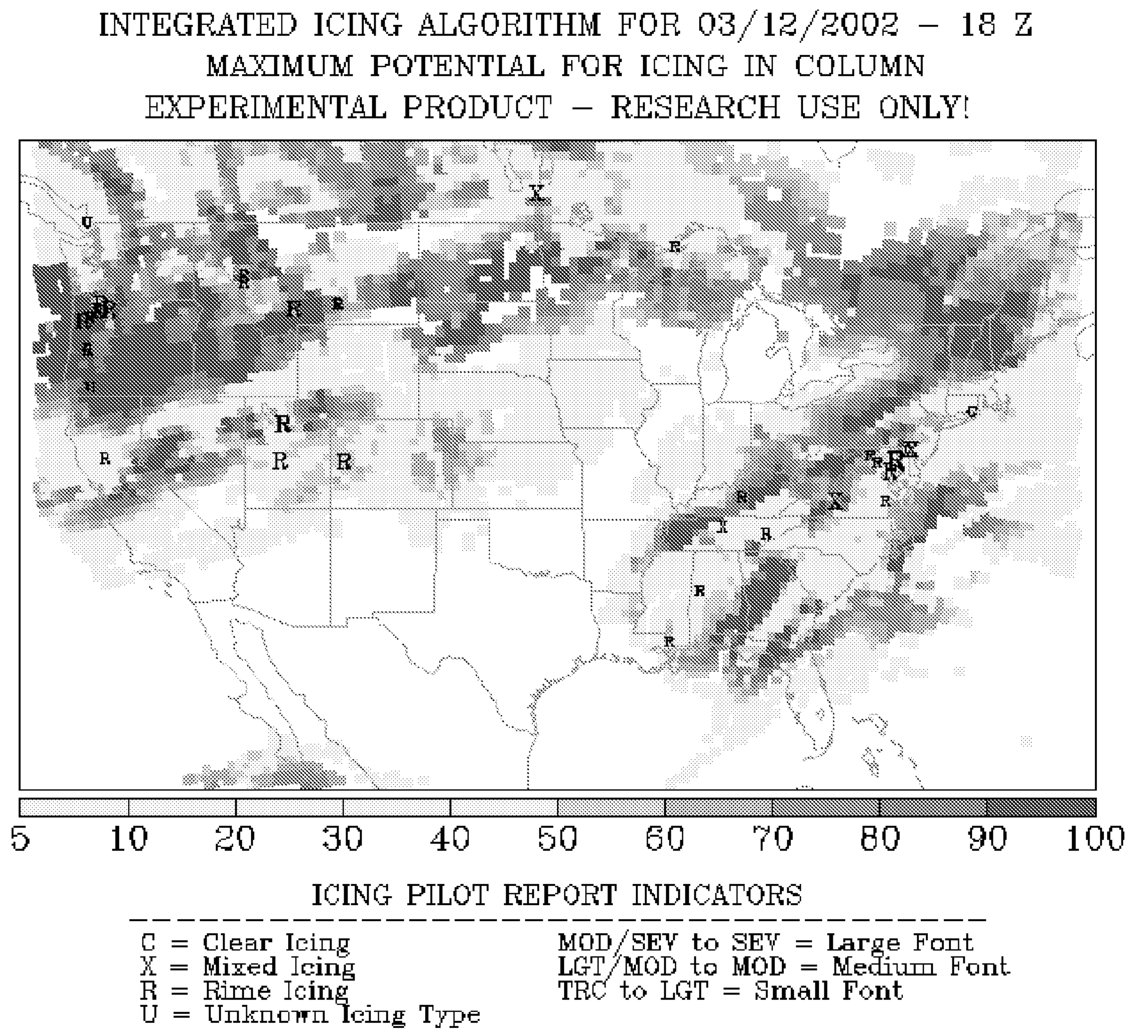

Figure 1. Representative IIDA Diagnosis of Icing Potential

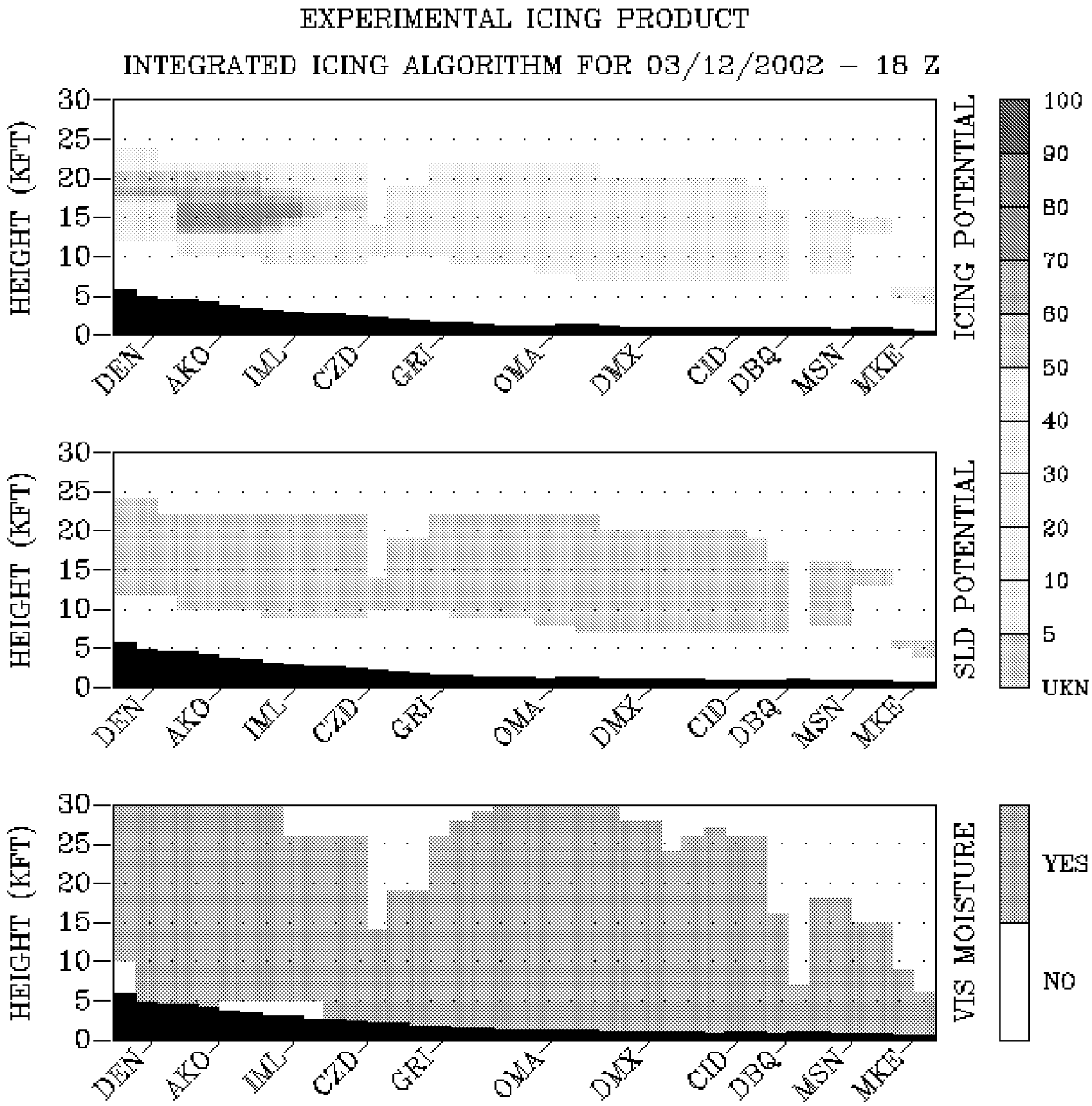

Figure 2. Representative IIDA Vertical Cross-sections

NCAR's Integrated Icing Forecast Algorithm (IIFA) is a forecast version of IIDA and is meant to mimic to IIDA information integration techniques. Since many of the IIDA observations are not available for three to twelve hours in the future, IIFA creates surrogates for each input data field, based upon output from the RUC (Rapid Update Cycle) model (for a detailed explanation, see http://www.rap.ucar.edu/largedrop/iifa/iifa_concept.explain).

Evaluations of the IIDA with regional airline flight dispatchers identified the tendency for the algorithms to be conservatively biased (i.e., to sometimes forecast icing where it does not materialize) (FAA, 2000). The evaluations also identified the need to add icing severity as an output. The addition of downlinked icing reports could improve IIDA's (as well as IIFA's) performance.

Project Objectives

The goal of this research project was to investigate the use of downlinked icing data to improve the IIDA and the IIFA products. There exist both technical and economic barriers in the way of a successful implementation of this concept. Only aircraft with both ice detection equipment and the appropriate databus and communications infrastructure can provide icing data. The set of aircraft meeting both of these criteria tend to be modern commercial turbojet aircraft that are certified to operate in all but severe icing conditions and generally are exposed to significant levels of in-flight icing for only a short period of time. For the operators of these aircraft, it may be difficult to justify the costs to retrofit the aircraft with icing downlink capability and the recurring communication costs. Thus the focus of this project was on improvements to IIDA and IIFA that could benefit major airlines. This focus provided a side benefit to NCAR in that previous evaluations focused on the regional carriers (FAA, 2000) while this research focused on the needs of a major carrier.

The objectives for this research were three-fold:

1. Without overlapping with the FAA's efforts along these lines, to provide information concerning in situ icing assessment and reporting based on the constraints of our airline participant, Delta Air Lines.
2. To investigate the integration of in situ data from multiple aircraft into the IIDA and IIFA products.
3. To determine the utility of the upgraded icing products for use by major air carriers, specifically DAL. The idea here was to investigate the utility of the improved icing products to DAL in order to identify an incentive to participate in the downlink program as well as to provide NCAR with feedback concerning their products from a new set of potential users.

This research provides progress toward these objectives by:

- Selecting an aircraft platform capable of digitally capturing, processing and downlinking icing data,
- Identifying the required in situ icing data processing,
- Determining the requirements for routing the icing data to NCAR for use by the IIDA and the IIFA products,
- Developing an icing case study in order to gain insight into major air carrier needs,
- Developing and prototyping icing display concepts for major air carriers based on NCAR's IIDA and IIFA, and
- Conducting a usability study for the prototyped concepts at a major air carrier.

Work Carried Out

We achieved the objectives by accomplishing the following tasks:

- Selecting an aircraft platform capable of digitally capturing, processing and downlinking icing data,
- Identifying the required in situ icing data processing,
- Determining the requirements for routing the icing data to researchers,
- Developing an icing case study in order to gain insight into major air carrier needs,
- Developing and prototyping icing display concepts, and
- Conducting a usability study for the prototyped concepts.

Platform selection

The purpose of this task was to identify a candidate aircraft that has both ice detector data available on the aircraft data bus and downlink capability. Ideally the ice detector output is available on the aircraft data bus, accessible to non-safety critical avionics with modifiable software. In this way, the non-safety critical avionics can serve as a host for the icing software.

At Delta Air Lines, most aircraft have downlink capabilities, although aircraft, such as the B727, with three person crews do not (Table 1). DAL aircraft are equipped with anti-ice protection systems that prevent the formation of ice on wings and engines, assuming the aircraft only encounters ice in the range specified by FAR Part 25, Appendix C.

Table 1. DAL fleet ACARS equipage and ice detection

Aircraft type	ACARS	Ice detector model
B-737-200	Yes	To be determined (TBD)
B-737-300	Yes	TBD
B-737-600/700/800	Yes	TBD
B-757-200	Yes	BFG's 0871BN3-4 or 0871BN3-10
B-767-200	Yes	BFG's 0871BN3-4/10 (advisory) or 0871DL6 (primary)
B-767-300	Yes	BFG's 0871BN3-4/10 (advisory) or 0871DL6 (primary)
B-767-300ER	Yes	BFG's 0871BN3-4/10 (advisory) or 0871DL6 (primary)
B-767-400ER	Yes	TBD
B-777-200	Yes	BFG's 0871DL6
MD-11	Yes	BFG's 0871GD1
MD-88/90	Yes	Vibrometer's VS3960

Most of DAL's aircraft use a variant of BFGoodrich Aircraft Sensors Division's (BFG's) model 871 (Table 1). The BFG model 871 outputs a digital "ice/no ice" signal. The ice signal output is a switched high impedance to ground capable of sinking a 100 mA load. The icing signal feedback circuit functions when the high impedance output state is pulled up to 10 volts minimum. A low impedance output of 20 ohms or less signifies icing. Under non-icing conditions, the output is 100K ohms or greater. The output signal latches "on" for 60±10 seconds. The duration is reset to 60 seconds if an icing signal is encountered before the initial 60 seconds have expired.

According to the manufacturer, the sensor does not provide an indication of ice until approximately 0.020 inch of ice has accumulated on the sensor probe. As soon as the ice signal is activated, a heater comes on to melt the ice off the probe in less than 15 seconds. The sensor then begins sensing ice again. According to the manufacturer, for most icing conditions, the time to de-ice the probe and to start sensing a new icing encounter is 5-7 seconds. Once the ice is debonded from the probe, a timer in the software leaves the heater on for an additional 5 seconds. Typically the ice debonds in 1-2 seconds. When the temperature is –20°C to -30°C, the de-ice time can increase to 10 to 12 seconds. With model 0871BN8, if the heater is on longer than 20 seconds, the ice detector will indicate a fault.

The icing signal output determines a bound on the resolution of a sensed icing event. There is nothing to be gained by polling the output any sooner than it will update. Thus the expected horizontal resolution depending on current ice detection systems is on the order of 4 nautical miles at low altitudes (based on a detector latching on for one minute of flight at 250 knots below 10,000 feet) and about twice that figure at higher altitudes. The expected vertical resolution will be subject to small measurement errors in cruise. However, in climb or descent, the resolution decreases by approximately1000-2000 feet (assuming a 1000-2000 feet/minute climb or descent rate).

Given the positive results of the ice detector and ACARS capability analysis, the remaining issue surrounded identifying what aircraft could easily host the icing data processing and downlinking software. Initial discussions with DAL's avionics engineers identified the fact that the B777 aircraft possesses a unique integrated system that has the capability of collecting data and downlinking reports. The icing reports could be created by updating the user modifiable software onboard the B777. Thus without requiring expensive avionics upgrades, icing data from Delta's B777 aircraft could easily be sent to the ground.

To achieve the processing and downlink capability, DAL would have to modify the Aircraft Condition Monitoring Function (ACMF) software to report specified criteria. DAL maintenance would have to upload the new software on the B777 aircraft. At no cost to NASA or to Search Technology, Delta Air Lines created a schedule and budget that included software engineering, testing, and aircraft installation. Assuming that the requirements for the icing processing are well-defined, the schedule allowed for two cycles of development, a prototype build and a final build. That effort resulted in a labor hour estimate of 400 hours and a total project cost of $40,000.00. The details of the schedule and budget are available upon request.

In situ icing data processing

Even though we recognize the value of real-time reporting of atmospheric parameters by commercial airlines to improved weather diagnoses and forecasts, recurring communication costs via the ACARS network need to be considered before specifying what is downlinked and how often. Currently, airlines that participate in the Meteorological Data Collection and Reporting System (MDCRS) agree to pay the additional communication costs associated with weather reports. As a result, airlines limit the spatial and temporal resolution associated with reporting winds and temperature through the MDCRS network to save airborne and ground transmission costs. Although there are initiatives within the FAA and National Weather Service to have the government subsidize some of these costs, it is unlikely this will happen soon. Therefore, reporting frequency and message length will continue to be driven by economic concerns and not value of the data to improving the quality of weather information and benefit to the industry.

Airlines negotiate a per message cost through the ARINC ACARS network which is generally not divulged to the public or other airlines. However, to give some perspective on the extent of the costs and how they are determined, the following general information is provided:

- ARINC CONUS costs are about $.025 per block of 125 characters. International costs are on the order of $.59 per block of 220 characters.
- A three hour domestic flight will generate about 30 MDCRS reports, costing approximately $1.20. A 12 hour international flight will generate about 106 reports costing about $85. A major carrier with 2000 flights per day would spend (approximately) over $7M per year on MDCRS reports if all flights are turned on and report according to ARINC Specification 620 standards. In reality, airlines modify the reporting frequency from ARINC 620 and do not have all flights report to save ARINC communication costs.

The above costs assume the use of ARINC 620, which creates a report every 3 minutes (default), buffers 5-10 reports, and downlinks the bundle every 5-10 minutes. Most airlines do not use the ARINC 620 strictly, simply because it inefficiently uses the data blocks and increases communication costs. It also should be noted that these costs are approximate, as different airlines have varying agreements with ARINC relating to message volume.

Table 3 provides a printed report example and Table 4 provides an ACARS example of the modified ARINC 620 Specification (actually it is called ARINC 618, modified to incorporate a turbulence field used by United Airlines). A similar specification would have to be developed to include an icing parameter. The sample specification illustrates the problem associated with adding additional parameters without fully understanding the derived benefit and impact to message length. In the CONUS, the message block size is 125 characters and the cost per block is a flat $.025. Therefore, ACARS messages are formatted using multiple blocks. If a message is only one character over 125, the cost per message doubles. For the example ARINC 618 Specification, four weather reports are bundled in each actual downlink to maximize the use of two data blocks (250 characters). 210 characters, including flight identification and ARINC header, make up the two block downlink leaving 40 characters available for an icing field. This would suggest up to 10 characters are available for an icing field per weather report *in the CONUS*. However, considering a single data block for international reports is only 220 characters, only 10 characters are available to icing before exceeding the 220 block size. To quantify the impact on cost of exceeding block size, per message costs would double.

The ARINC 620 Specification is currently being modified to incorporate water vapor mixing ratio and turbulence, in accordance with the RTCA AUTOMET Minimum Operational Performance Standards (MOPS). The new standard will presumably also comply with ICAO Annex 3 standards for downlink weather reports. Field sizes for the various icing parameters being considered for downlink are:

- Water vapor mixing ratio, 4 characters.
- Icing indicator, Boolean, 1 character.
- Peak and average liquid water content, 2 characters each.
- Humidity, 2 characters.

Table 3. Print Format for the Weather Report

```
      0000000001111111111222222222233333333334444444444555555555566666
      1234567890123456789012345678901234567890123456789012345678901234
 01                                                                     01
 02                 WEATHER REPORT  <50>                                02
 03                                                                     03
 04   RPT TRG DVER ACID FLT  DEPT DEST DATE   GMT  FM                   04
*05   E22 C   99   999  9999 AAAA AAAA MMDDYY HHMM AA                   05
 06                                                                     06
 07   LAT     LON      GMT  ALT    SAT   WD  WS  TIND                   07
*08   SDDMM.M SDDDMM.M HHMM S99999 S99.9 999 999 0000                   08
*09   SDDMM.M SDDDMM.M HHMM S99999 S99.9 999 999 0000                   09
*10   SDDMM.M SDDDMM.M HHMM S99999 S99.9 999 999 0000                   10
*11   SDDMM.M SDDDMM.M HHMM S99999 S99.9 999 999 0000                   11
 12                                                                     12
      0000000001111111111222222222233333333334444444444555555555566666
      1234567890123456789012345678901234567890123456789012345678901234
```

Notes:

1. Report Format Characters: "A" is an Alphanumeric, "9" is a numeric, and "S" is a sign indicator. 0 is a padded character "0".
2. Report lines, which have an asterisk ("*") on the left hand side are to be downlinked when the Report's Output destination is ACARS.
3. The header line (Line 05) is snapshot at the time of the report trigger.
4. It is possible that four weather points are not collected prior to the end of a Weather phase (e.g., Ascent). For this case, only the collected lines are downlinked.
5. The "S" sign for altitude and static air temperature (SAT) is defined below:
   - Negative Sign is "M"
   - Positive Sign is "P".
6. The "S" sign for latitude (LAT) and longitude (LON) is defined below:
   - LAT negative value is SOUTH or "S"
   - LAT positive value is NORTH or "N"
   - LON negative value is WEST or "W"
   - LON positive value is EAST or "E".
7. Other field names and formats appear in Table 4.

Table 4. ACARS Format for the Weather Report

Data Sent	Char	Data	Scale
STANDARD ACARS HEADER	1-19		Reference: Honeywell Product Specification - Common Functions - 967-0212-601, Section 4.9.3.1.3.
E22	20-22	E22	E22 (Weather report ID)
TRG	23	C	C (computer generated)
DVER	24-25	99	ACMS Database version
ACID	26-28	999	Aircraft Tail Number
FLT	29-32	9999	Flight Number
DEPT	33-36	AAAA	Departure
DEST	37-40	AAAA	Destination
DATE	41-46	MMDDYY	Date (Month, Day, and Year)

Data Sent	Char	Data	Scale
GMT	47-50	HHMM	GMT time (Hours and Minutes)
FM	51-52	AA	Flight Mode
CR	53	<CR>	Carriage Return
LF	54	<LF>	Line Feed
LAT 1	55-60	SDDMMM	Latitude S/N XX Degrees XX.X Minutes
LON 1	61-67	SDDDMMM	Longitude W/E XXX Degrees XX.X Minutes
GMT 1	68-71	HHMM	GMT time (Hours and Minutes)
ALT 1	72-77	S99999	Altitude P/M XX,XXX Feet
SAT 1	78-81	S999	Static Air Temperature P/M XX.X Degrees C
WD 1	82-84	999	Wind Direction XXX Degrees
WS 1	85-87	999	Wind Speed XXX Knots
TIND 1	88-91	0000	Turbulence Indicator (Padded and sent as Zeros) “0000”
CR	92	<CR>	Carriage Return
LF	93	<LF>	Line Feed
LAT 2	94-99	SDDMMM	Latitude S/N XX Degrees XX.X Minutes
LON 2	100-106	SDDDMMM	Longitude W/E XXX Degrees XX.X Minutes
GMT 2	107-110	HHMM	GMT time (Hours and Minutes)
ALT 2	111-116	S99999	Altitude P/M XX,XXX Feet
SAT 2	117-120	S999	Static Air Temperature P/M XX.X Degrees C
WD 2	121-123	999	Wind Direction XXX Degrees
WS 2	124-126	999	Wind Speed XXX Knots
TIND 2	127-130	0000	Turbulence Indicator (Padded and sent as Zeros) “0000”
CR	131	<CR>	Carriage Return
LF	132	<LF>	Line Feed
LAT 3	133-138	SDDMMM	Latitude S/N XX Degrees XX.X Minutes
LON 3	139-145	SDDDMMM	Longitude W/E XXX Degrees XX.X Minutes
GMT 3	146-149	HHMM	GMT time (Hours and Minutes)
ALT 3	150-155	S99999	Altitude P/M XX,XXX Feet
SAT 3	156-159	S999	Static Air Temperature P/M XX.X Degrees C
WD 3	160-162	999	Wind Direction XXX Degrees
WS 3	163-165	999	Wind Speed XXX Knots
TIND 3	166-169	0000	Turbulence Indicator (Padded and sent as Zeros) “0000”
CR	170	<CR>	Carriage Return
LF	171	<LF>	Line Feed
LAT 4	172-177	SDDMMM	Latitude S/N XX Degrees XX.X Minutes
LON 4	178-184	SDDDMMM	Longitude W/E XXX Degrees XX.X Minutes
GMT 4	185-188	HHMM	GMT time (Hours and Minutes)
ALT 4	189-194	S99999	Altitude P/M XX,XXX Feet
SAT 4	195-198	S999	Static Air Temperature P/M XX.X Degrees C
WD 4	199-201	999	Wind Direction XXX Degrees
WS 4	202-204	999	Wind Speed XXX Knots
TIND 4	205-208	0000	Turbulence Indicator (Padded and sent as Zeros) “0000”
CR	209	<CR>	Carriage Return
LF	210	<LF>	Line Feed

Notes:

1. Report Format Characters: "A" is an Alphanumeric, "9" is a numeric, and "S" is a sign indicator. 0 is a padded character "0".
2. Decimal points are removed from ACARS message.
3. The "S" signs for Altitude and SAT is defined below:
   - Negative Minus Sign is " M"
   - Positive Plus Sign is "P".
4. The "S" signs for LAT and LON is defined below:
   - LAT negative value is SOUTH or "S"
   - LAT positive value is NORTH or "N"
   - LON negative value is WEST or "W"
   - LON positive value is EAST or "E".

Considering the United Airlines ARINC 618 format, it would seem that any icing field could be included without exceeding two data blocks during CONUS flights. For international reports, only the Boolean indicator is possible. It is improbable that all airlines will comply with the new ARINC 620, so at this point it is difficult to make a judgment as to which icing parameters are both economically and technically feasible.

To summarize the preceding analysis:

- The Boolean icing indicator appears to be technically and economically feasible for both CONUS and international weather reports. It has informational value to integrated in flight icing algorithms. Most likely there is no value to numerical weather prediction (NWP) models as such models are designed to handle physical units (atmospheric data) and would require significant modification to incorporate the icing data.
- Peak and average liquid water content, together, would be economically feasible for the CONUS. However, costs would double for international reports. Technically, there is some risk in the sensor development and attainable accuracy. These parameters should have value to both integrated in flight icing algorithms and NWP models.
- Operational humidity sensors have a limited life and may introduce quality control issues. However, humidity (2 characters) might be feasible if reporting frequency is decreased.
- Water vapor sensors are being installed on a limited number of commercial aircraft. This program may expand to include many aircraft, and is government funded (including communication costs). The exact scope of the program that is approved and funded is unknown at this time. Since communication costs are not paid by the airlines, the block size issue goes away.
- The analysis suggests that an icing parameter field should be added to whatever ARINC Specification is being used by a particular carrier (for example, ARINC 618). If the block size is exceeded (say for an international report), one way to decrease the number of characters needed for any parameter is to use hexadecimal representation of a "bin" or range of values. This technique is being used for downlinking turbulence. Further analysis would be needed to optimize definition of the bin values so that accuracy of the data is not compromised.

Routing of the icing data

The operational concept assumes that in situ icing data from aircraft can be downlinked to the ground and can be available for use by NCAR's IIDA and IIFA products. Search Technology contacted ARINC to investigate the routing of the icing data to NOAA (the Forecast Systems Lab in Boulder). NCAR already receives the MDCRS data from NOAA so this strategy eliminates creating a new data network just for NCAR.

ARINC responded that the creation of the routing mechanism for a new datalink message is very easy. Basically a new identifier is created and a new entry is added to a routing table. The cost for ARINC to create the identifier and to add it to the routing table is small (perhaps they would even do it at no cost to NASA, Search Technology, or to Delta Air Lines). This is not surprising, as ARINC would still make a profit from the new data stream.

Icing case study

To help understand the icing data needs of major airlines, an icing case study was developed based on the March 20, 2000 icing event at Denver International Airport. On that day, hundreds of major air carrier and commuter flights were diverted or cancelled because of the lack of appropriate weather information. Cancellations were caused by the severity of the reported icing conditions. In addition, ground based deicing was overwhelmed by the amount of ice on aircraft that had landed. There were also a few serious icing encounters.

Reports of icing began with the first operations out of Denver on the 20th. NWS AIRMETs for moderate rime and mixed icing for Denver were issued as early as 0900Z. At least three reports went out between 1300Z-1400Z: one for light-moderate rime, one for moderate ice (no type), and one for moderate clear. Icing intensified as the morning went on, and peaked in the 1600Z-1700Z time frame.

The NWS issued SIGMET Oscar 1, calling for severe rime/mixed ice below FL150, at 1615Z. The SIGMET, valid from 16:15Z to 20:15Z (and beyond), was for occasional severe rime/mixed icing in clouds and in precipitation below 15,000 feet. Figure 1 depicts the area covered by the SIGMET. The text of the SIGMET follows:

WSUS1 KSLC 201615
WS5O
SLCO UWS 201615
SIGMET OSCAR 1 VALID UNTIL 202015
WY CO
FROM BFF TO GLD TO PUB TO 50S HBU TO CHE TO 40NW LAR TO BFF
OCNL SEV RIME/MXD ICGICIP BLW 150. CONDS CONTG BYD 2015Z.
PCF

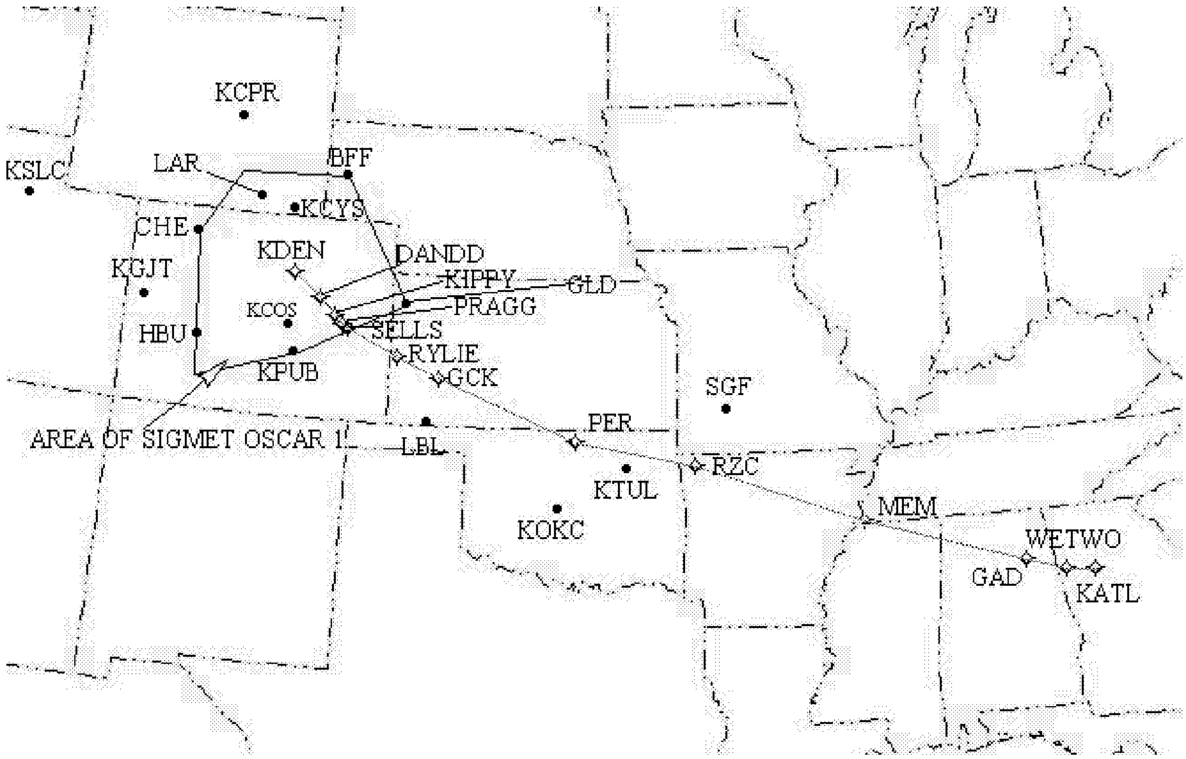

Figure 3. ATL-DEN Flight Plan and SIGMET Oscar 1

During the peak icing period, many landing and departing aircraft reported at least moderate ice, with some severe. Based on flight dispatcher comments, all of the arrival gates were experiencing icing. Some representative pilot reports include (aircraft identifiers removed to preserve anonymity):

1554Z IC LGT MIXED DURGC FL070-110

1629 IC LT ICING THRU FL080 BROKE OUT AT FL110

1647 IC MDT RIME DURGD FL110-100 MDT-SVR BELOW THAT

1655 IC MDT-SVR ICE FINAL RWY35R ALSO HAD TO KEEP ENGINE RUN UP ON APPROACH

1722 IC MDT MIXED DURGD FL095-070 R35R

1731 DEN-BOI NO PROBLEM COORDINATING EXPEDITIOUS CLIMB ABOVE ALL ICING PROBLEMS. CLIMBOUT WAS FINE WITH MINIMAL ICE BUILDUP.

1735 IC MDT MIXED FL080-070 -RA BELOW 070

IC MOD RIME BELOW 10000FT ON FINAL

IC MDT MIXED DURGD FL110-070 R34R

There were numerous voice reports of icing made directly to air traffic controllers and to airline flight dispatchers. Comments to flight dispatchers included the following: 5.5 inches of ice on the glare shield, could not retract flaps due to ice buildup, ice on all tail surfaces, and 2-3 inches of ice on the aircraft.

To help develop a scenario for the case study, Delta Air Lines provided a set of flight plan, weather briefing and related data for aircraft flying into Denver before and during the time of interest. For the icing case study, we generated a flight plan and weather briefing data for a Boeing 757-200 flight, ACME 9999, from Atlanta to Denver. Figure 1 depicts the route of flight. See Appendix A for flight plan and weather briefing details and Appendix B for the locations for many of the referenced airports and navigational aids.

Weather related data for this event had been archived by NCAR and was available for analysis. NCAR created a web site with the archived data for the March 20, 2000 case study: www.rap.ucar.edu/largedrop/2000mar20case/case.html

The web site included:

- Satellite imagery,
- Radar imagery,
- METARs (See http://www.nws.noaa.gov/oso/oso1/oso12/fmh1/fmh1toc.htm for observing, reporting, and coding standards for surface based meteorological reports),
- PIREPS (See http://www.ifis.airways.co.nz/shtml/planning/designators.shtml for aircraft type designators),
- Sounding and profiler data,
- AIRMETS and SIGMETS, and
- IIDA plots.

Of particular interest to this project was the fact that the icing conditions were for altitudes well below typical cruise altitudes for all aircraft in a major carrier's fleet. Data from such an event would only be relevant when aircraft are in the terminal area, (either departing or arriving), or on the ground.

Icing display prototype development and evaluation

In this effort, the focus was to develop and to evaluate a display to help flight dispatchers with their icing related decisions. This section is divided into the main sections: the display concept and the usability study.

Display Concept

Flight Dispatcher's Icing Decision Making

Before developing the display concept, several flight dispatchers were interviewed at Delta Air Lines in order to gain a better understanding of their icing related decisions. Each work day, a flight dispatcher is responsible for a set of flights. At the beginning of a shift, flight dispatchers are generally provided with a duty roster identifying the flights. Depending on the time of day that a shift begins, flights require different actions. Some of these flights may already be in progress and therefore require monitoring. Others may be at the gate with an initial flight plan on file and the dispatcher may need to modify the plan if conditions have changed. Other flights may still need to be planned for the first time. Some flights may be scheduled so far into the future that it is still too early to plan them.

There are several icing related decisions that flight dispatchers make:

- Flight cancellation,
- Flight plan routing based on aircraft equipment and forecast weather,

- Alternate airport selection,
- Fuel load planning,
- Weight restriction considerations, and
- Flight following

As dispatchers plan flights well before scheduled pushback, they need good forecasts spanning the period from before the scheduled departure time to the scheduled arrival time (with cushions on either end for contingency planning). Dispatchers build in a margin of safety from icing conditions based on both the accuracy and recency of the forecast data. The more reliable the information, the less margin required. Due to the lack of complete current information, flight dispatchers may resort to contacting company aircraft that are in-flight for current weather conditions, particularly when forecast is old. For flight following, dispatchers need near real-time data. For a lot of these decisions, dispatchers preferred using PIREPs rather than forecast information because the PIREPs can be more reliable. However, when considering PIREPs, dispatchers must be concerned with the type of aircraft giving the report. For instance, they need to know if the airplane is a "hot wing" aircraft (i.e., an aircraft that uses engine bleed air to heat the leading edge) or an aircraft with inoperative equipment, unequipped to handle icing conditions.

With equipped aircraft, a major concern for dispatchers is inoperative equipment. The dispatcher must consider:

- What is wrong with the aircraft?
- What types of icing conditions must this aircraft avoid?
- What route and at what altitude can I safely plan for this flight?
- If the altitude is restricted, what related changes do I have to make?

For example, for Delta Air Lines aircraft, inoperative equipment can be in the form of inoperative engine or wing anti-ice valves. The type of failure necessitates different actions. An inoperative wing anti-ice valve means that "hard ice" is a problem where an inoperative engine anti-ice valve means that "soft ice" must be considered. "Hard" ice occurs between 0 and -40° C in visible moisture, and where "soft" ice (ice that can form once air is cooled) can occur if the temperature is between 10 and -20°C and when the humidity is high (Myszkowski & Rezsonya, 1996). Thus, the available route and altitude selections vary depending on the type of inoperative equipment. In most cases though, the engine ice or "soft ice" is considered more serious.

In order to plan flights through and around icing conditions, dispatchers at Delta use both PIREPs and forecasts, similar to the ones used by pilots. Unfortunately, many of the products that are commercially available (including the web sites listed in the pilot needs section) only show the potential for hard ice. In order to determine the potential for soft ice, dispatchers tend to use temperature dewpoint spread heuristics. More data and tools for determining the potential for engine icing would be helpful.

Flight Dispatcher's Icing Display Needs

Flight dispatchers at Delta Air Lines have a variety of computer support tools to help them do their job. Their workstation set up is comprised of three monitors with windows displaying different kinds of data. Figure 4 groups the available tools and data:

Weather Products(e.g., Company products; Airline Dispatchers Federation Weather Briefing Page)	Graphical Flight Following (e.g., Aircraft Situation Display)
Access to company databases such as: • ACARS messages • Flight plans • Flight schedules • Maintenance • Meteorology Alerts • Reservation system • Weather data (text)	Flight Dispatcher Flight Tracking • Flight planning status • Flight status • Maintenance status • …

Figure 4. Typical Flight Dispatcher Support Tools

At DAL, the flight dispatchers can access both company weather products as well as products available on the Internet (e.g., Airline Dispatchers Federation Weather Briefing Page). The flight dispatchers can open multiple windows for the display of weather products.

The flight dispatchers can view a graphical flight following tool displaying the position of aircraft in near real-time. The DAL flight following tool, based on ATC data, is updated approximately every seven minutes.

The flight dispatchers have access to company databases that include a wide variety of information such as legacy flight planning tools, company communications, crew and flight schedules, maintenance information, weight and balance information, company weather data and meteorology alerts, and flight status. Company communications include messages sent via ACARS to and from the flight crew. A decision support tool displays the set of flights assigned to the flight dispatcher and annotates data fields with status items such as whether the flight plan has been filed, whether the aircraft has left the gate, what time the aircraft took off, and other related data.

Flight dispatchers need tools that help them make flight planning decisions with respect to the effect that icing has on both equipped aircraft and aircraft with inoperative equipment. Both structural and engine icing conditions should be supported. They would like forecasts to be more accurate so they do not have to build in margins that end up costing the company more operational expense.

The flight dispatcher interviews and the icing case study discussed previously revealed that major airlines' flights generally spend a majority of their flight time above icing conditions. Based on interviews of flight dispatchers at DAL, it was determined that detailed icing information for the terminal area would be of the greatest value. At DAL, the flight dispatchers have relatively sophisticated workstations. They can display many weather products. However, they do not have good tools for viewing icing data in the terminal area. They can access IIDA on the ADDS web page and can hand draw routes in order to get the output tailored to a particular route. One positive aspect of ADDS is that it allows the integration of multiple sources of information and allows the ability to see PIREP text quite easily. However, the interface is slow and does not easily support viewing a single terminal area, let alone comparing several. For example, it is difficult to quickly zoom and add a new route. Also it is confusing to read the ADDS output as it is displayed linearly according to the order it is entered (rather than north up, for instance). Also, ADDS does not allow users to save the hand drawn routes. Flight dispatchers want tools that easily allow them to see if there is a path through the terminal area to the runway. Tools like ADDS, if they loaded quickly and were easy to use, would be of great value. Entering routes and waiting for them to load, however, can be laborious.

Displays tailored to Standard Instrument Departures (SIDs) and Standard Arrival Routes (STARs), the flight paths generally follow, could be of great value, especially if they allow the flight dispatchers to see if the icing is currently or is forecast to be along the route. However, flight dispatchers also need a regional view of the terminal area because aircraft do not always follow arrival and departure routes exactly. For instance, air traffic controllers can vector them around for traffic and other conditions. Information for a regional view should be available for altitude strata of concern as it is possible for aircraft to fly under or above the icing conditions.

To support flight planning for longer domestic flights, not only current information should be available but also 3, 6, 9 and 12 hours forecasts. To support international flights and decisions concerning whether an aircraft staying at a particular airport overnight can depart the next morning, even longer forecast periods are desirable.

Display Concept Example

Based on these notions, a set of integrated displays was designed for icing data in the terminal area. The idea was to have a horizontal, regional view that could be filtered to show altitude strata of interest. The idea was also to allow flight dispatchers to easily view the possibility for icing along SIDS and STARs.

The following example uses the terminal area at Cincinnati. Figure 5 shows a display of the main screen: arrivals are depicted as the default. Each arrival is labeled with its entry fix and is color-coded according to the legend. The airport, CVG, is marked with a square. The background can be toggled from arrivals to departures at the user's request. The bottom left portion of the display allows the flight dispatcher to request other views such as current and forecast icing or SLD data, either displayed in a composite view or by altitude strata. The bottom right portion allows selection of other icing related products tailored to the horizontal region of interest.

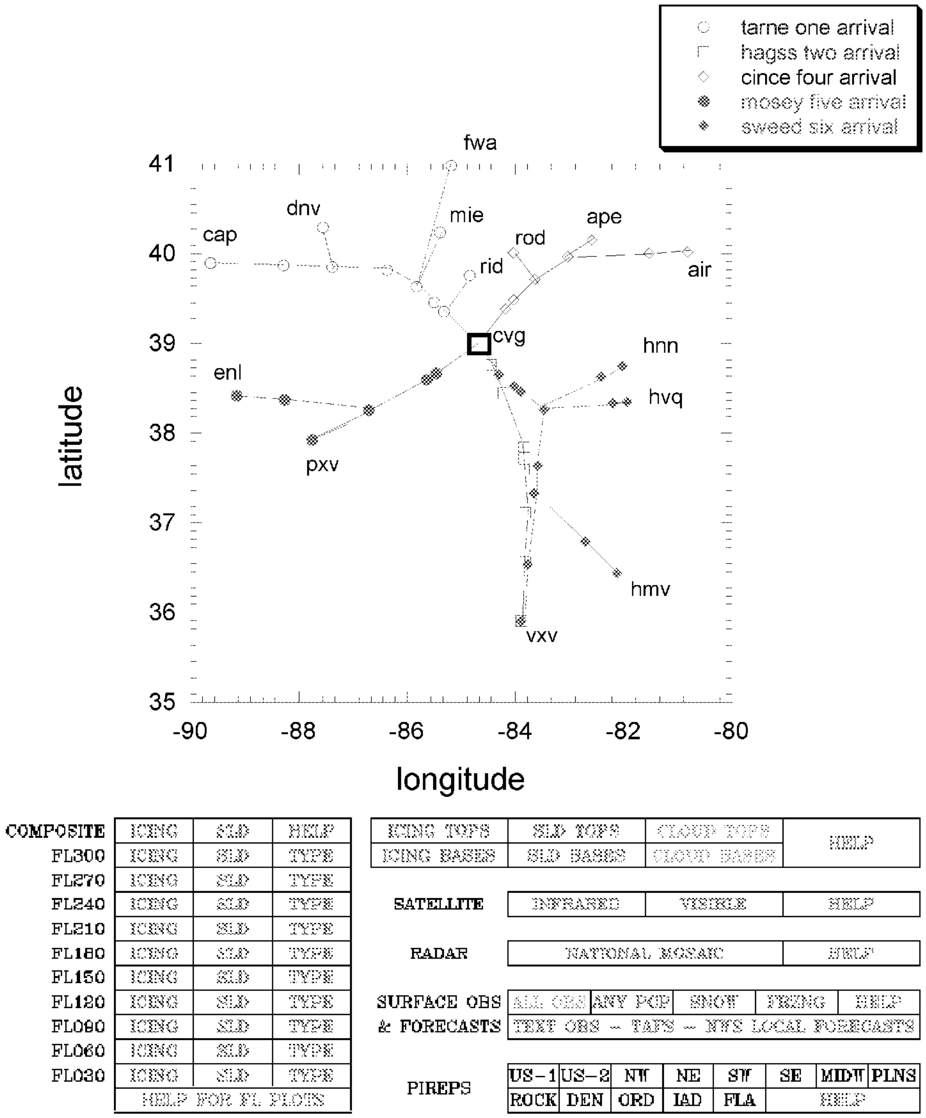

Figure 5. Regional view with airport arrivals overlay

The user selects the icing data to display from the arrivals display described above. Figure 6 illustrates the case where the flight dispatcher has selected the composite icing view. Although not depicted in the figure, a legend is available portraying the mapping of the color coding to the potential for icing. The darker the shading, the higher is the potential for icing. In this example, it is obvious that there is a potential for icing, especially in the northwest quadrant of the terminal area. To gain a better idea of the vertical extent of the icing potential, the user can select the flight level filters and/or select a particular route.

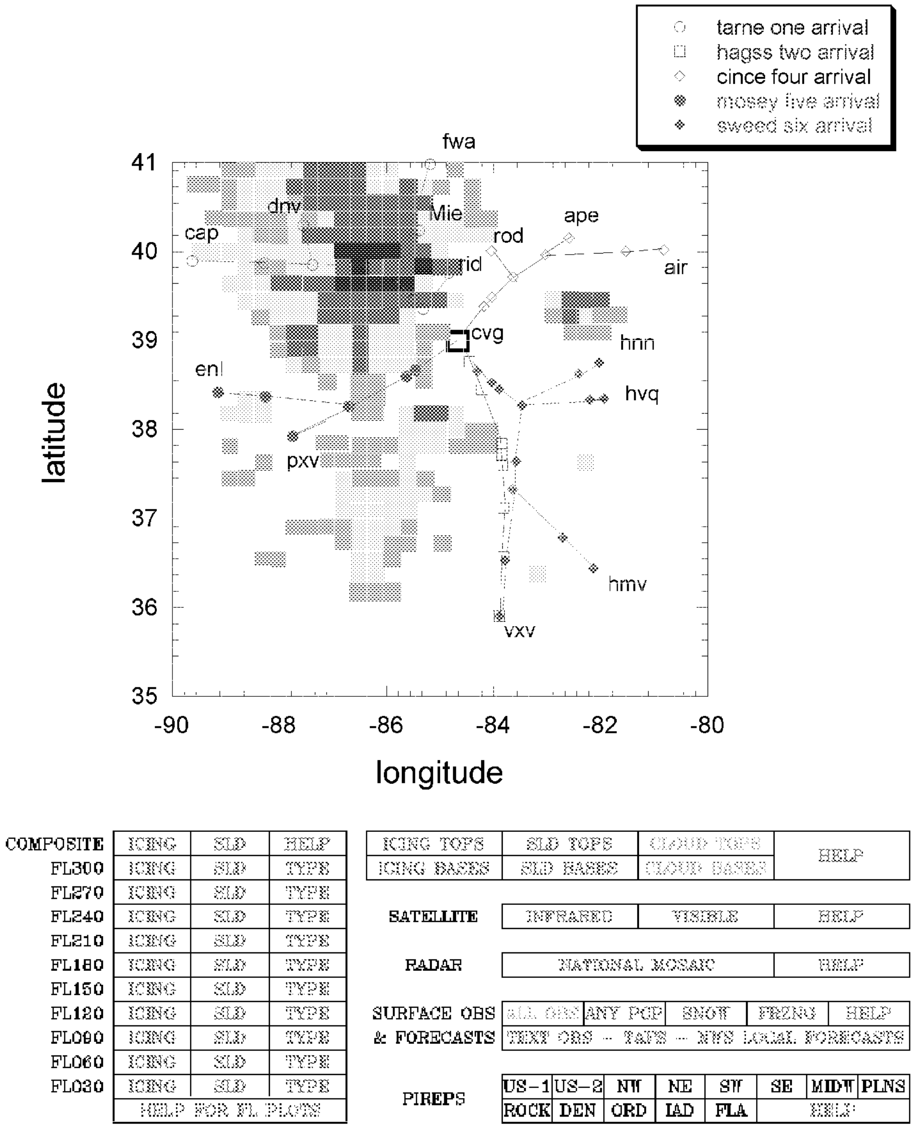

Figure 6. Regional view with airport arrivals overlay and example composite icing data

As part of the display concept, flight dispatchers can easily access a vertical cross-section view for any of the routes depicted on the main screen. Figure 7 is an example cross-section view for the MOSEYS arrival route. To avoid confusion concerning the linear layout, the entry fix is displayed to the left and the destination to the right. On the vertical cross-section display each rectangle covers a 1000 foot by 40 km area. The top figure presents the icing potential data. The display makes it clear what altitude an aircraft would have to fly to avoid the icing.

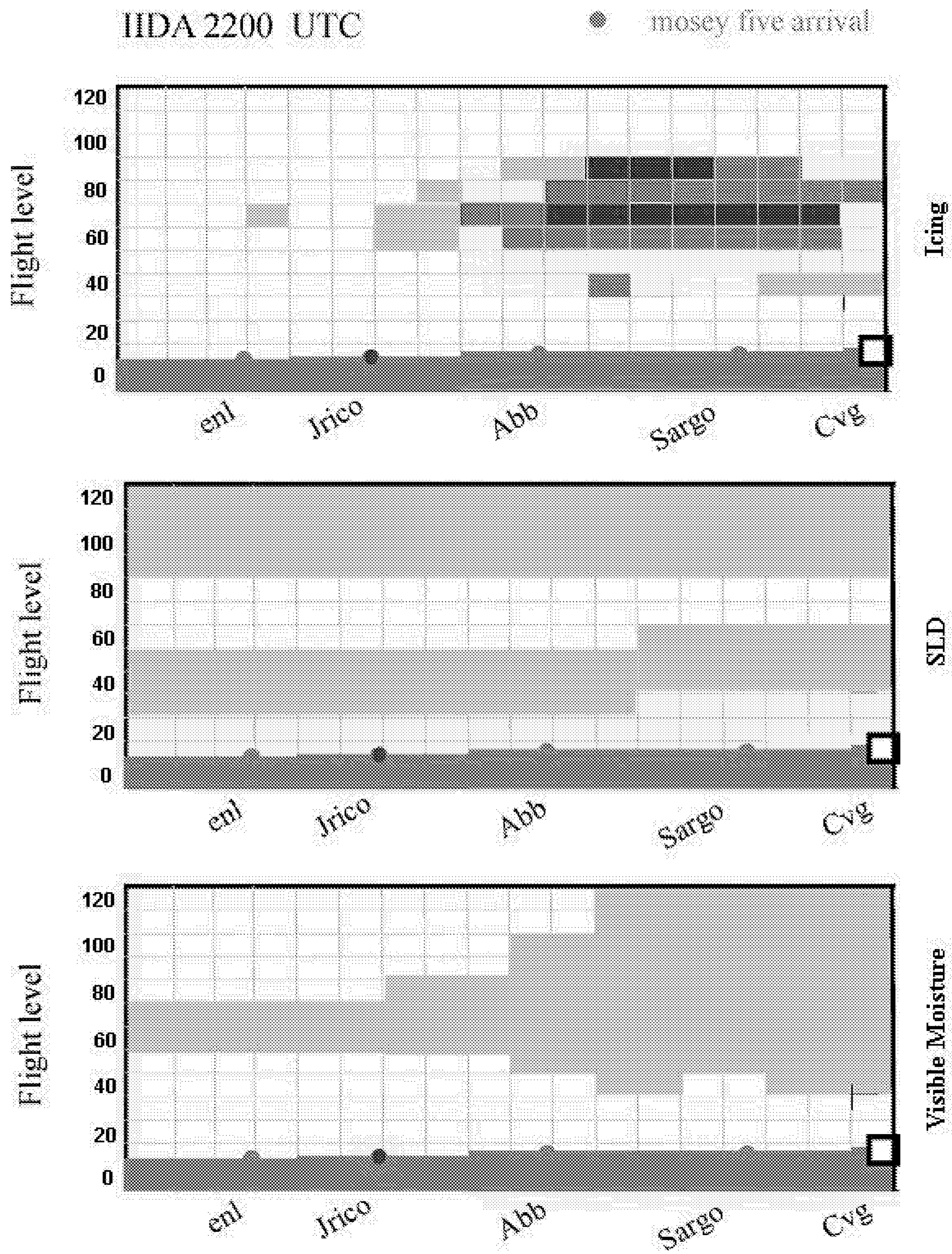

Figure 7. Example vertical cross-section display for the MOSEY5 arrival.

The middle of Figure 7 represents another vertical cross-section view (SLD) tailored to the arrival. The lower portion of the figure represents the location of visible moisture below 45° F.

Similar figures would be available for each arrival route. Similarly, departure routes would be available. In addition to these icing diagnostic displays, forecasts would also be available.

Usability Study

Although IIDA had been evaluated with regional carriers (FAA, 2000), the purpose of this study was to investigate the utility of IIDA and IIFA to flight dispatchers at major airlines. Based on the display concept described above, prototype displays were developed and a usability study was carried out. Our primary goal in the usability study was to find out if/how the displays should be refined.

Prototype displays

Because of the limited resources for this study, the idea was to prototype IIDA and IIFA displays for one SID and one STAR at one airport. NCAR implemented prototype displays for the Cincinnati/Northern Kentucky International Airport in Covington, KY (CVG) since this is a hub for our airline partner, DAL, and there is a relatively high frequency of atmospheric icing conditions. The prototype displays showed IIDA and IIFA output on plan view and vertical cross-sections. The displays operate on 'live' IIDA/IIFA data – that is, they were updated with current IIDA/IIFA output. The displays were implemented using HTML and were available over the Internet using a standard web browser.

Plan views (i.e. terminal scale views) were created of IIDA/IIFA output for an area approximately 840x1280 km centered on CVG. The main plan view included the composite IIDA output for current icing potential. The default main display showed stylized arrival routes. Although the intention was to draw every arrival route to scale (as in Figure 6), resource constraints forced the design to include simplified, straight-line arrival routes overlaid on this view (Figure 8). The composite icing view depicts a set of 40 km by 40 km areas where each area is color coded according to the highest icing potential for the vertical column associated with the area. To provide the ability for the flight dispatchers to gain an understanding of how the terminal area product could work, a single arrival route was linked to a vertical cross-section of that route (see the "+" at the bottom middle of Figure 8). The link was accessed by clicking on the "+" cross-hair at the end of the route shown on the display. PIREPs of icing were shown on each of these views as well. Other views (described below) were accessed through links at the bottom of these IIDA composite plan views.

A corresponding view was also created for the departures (Figure 9). As with the arrivals, a single route was implemented to provide the flight dispatchers with the opportunity to view an associated vertical cross-section (see the "+" on the middle right of Figure 9).

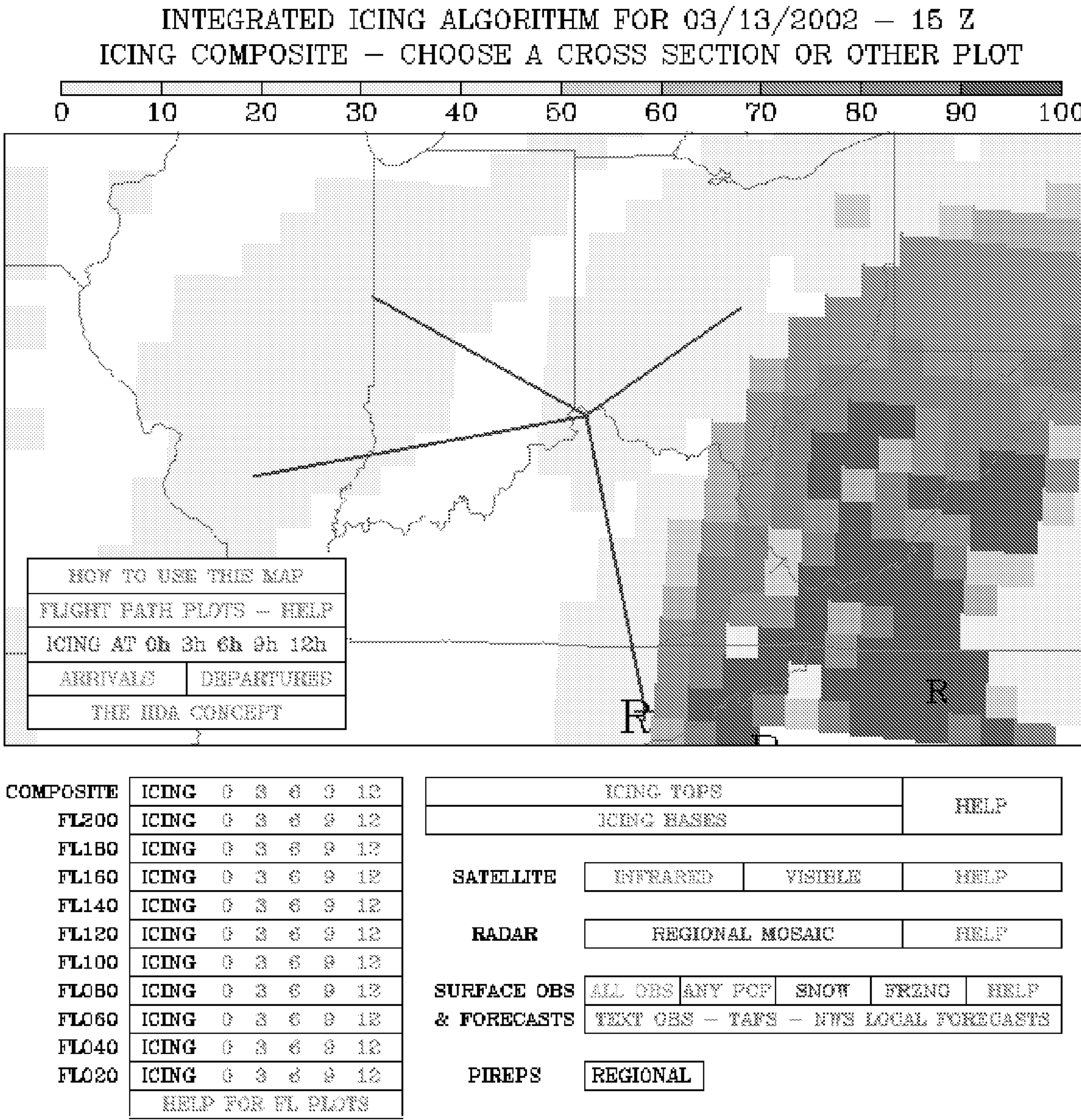

Figure 8. Implemented regional view with airport arrivals overlay

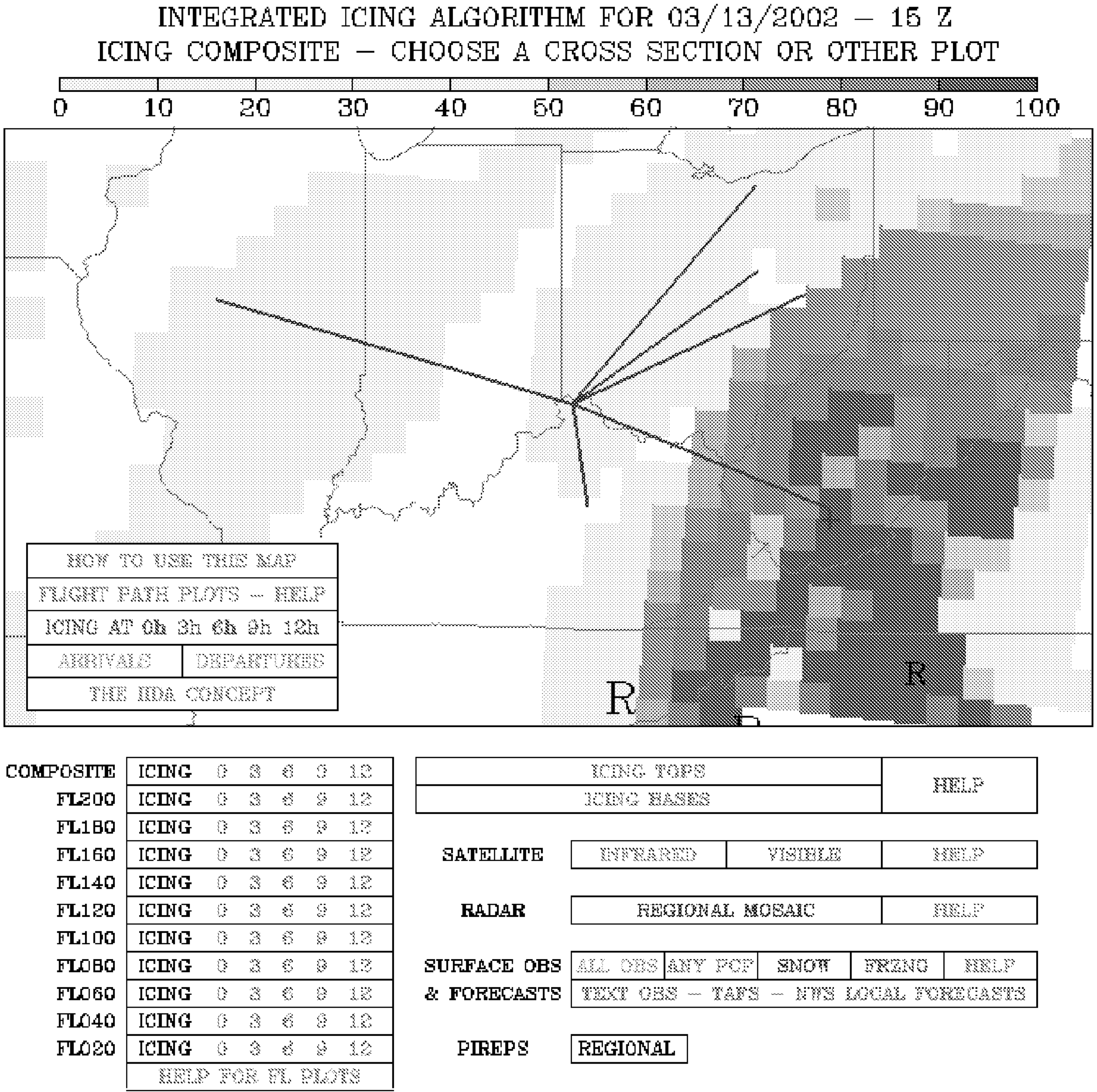

Figure 9. Implemented regional view with airport departures overlay

The terminal scale plan views implemented for the usability test also included IIFA output for horizontal cross-sections at 2000 foot increments from 2000 to 20,000 feet MSL with 3, 6, 9, and 12 hour forecasts. An example plan view centered on CVG that includes a 3 hour forecast for 8000 feet is shown in Figure 10.

To provide the flight dispatchers the opportunity to comment on access to related icing data, icing cloud bases and tops, current precipitation, freezing precipitation, and snow were implemented for CVG. An example display of icing cloud tops is shown in Figure 11. An example display of current precipitation is show in Figure 12.

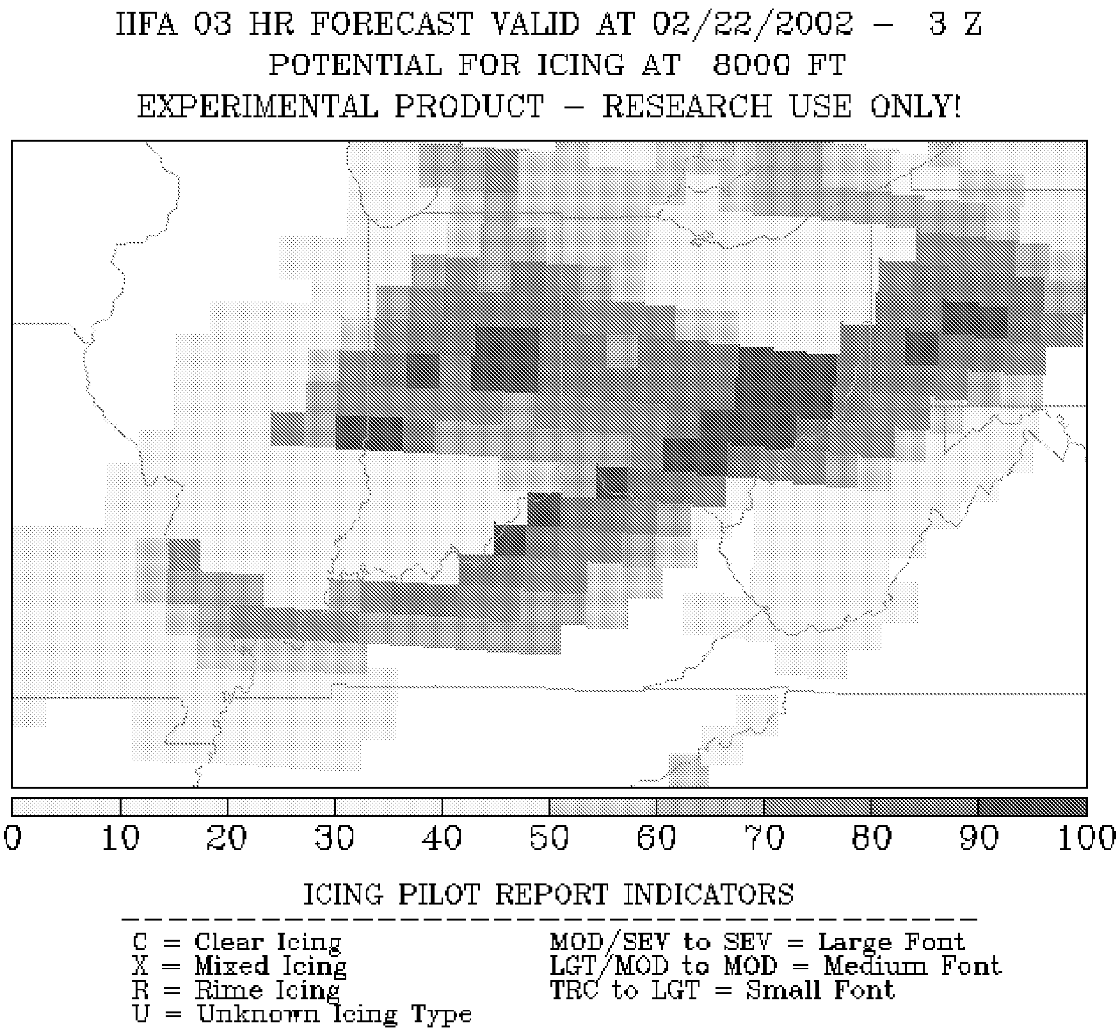

Figure 10. Implemented IIFA

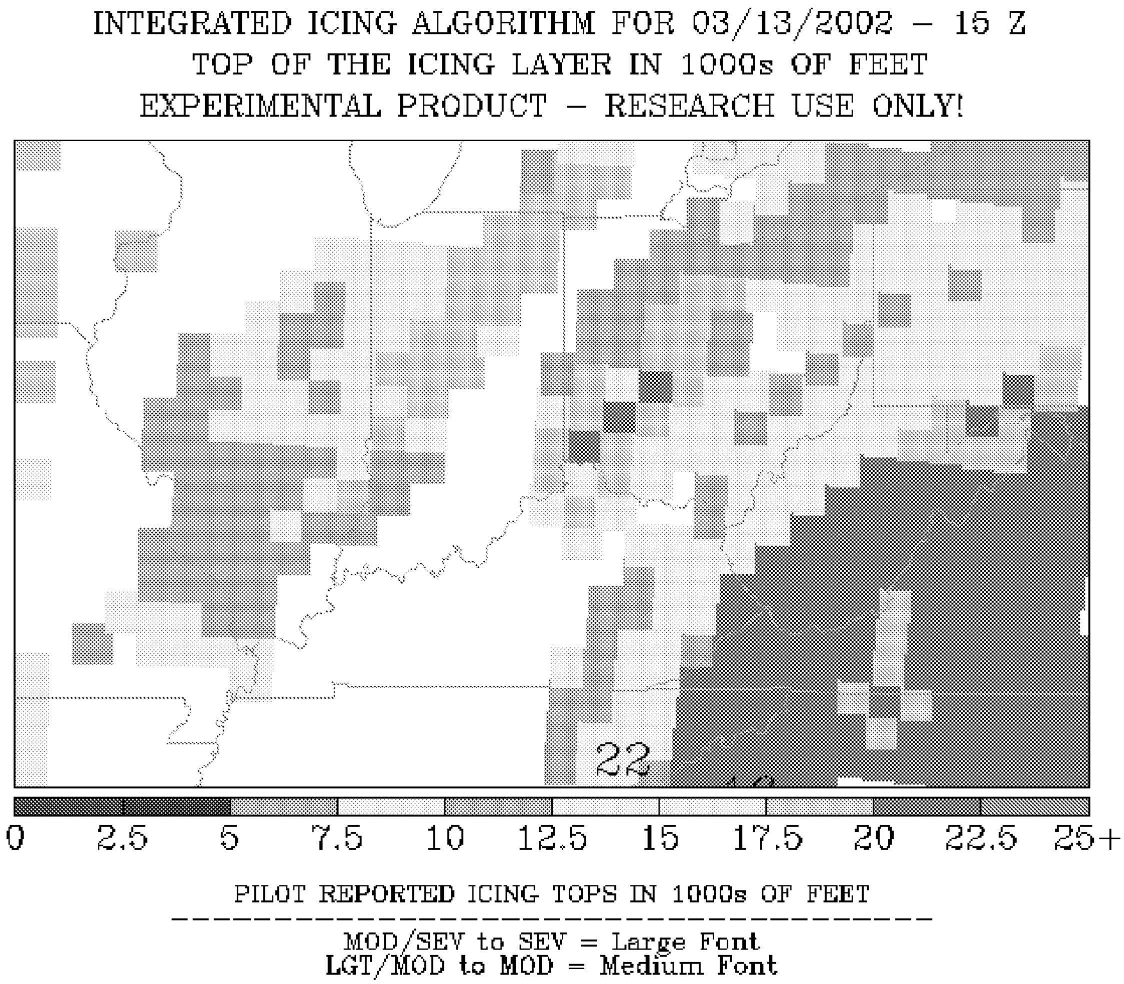

Figure 11. Implemented tops

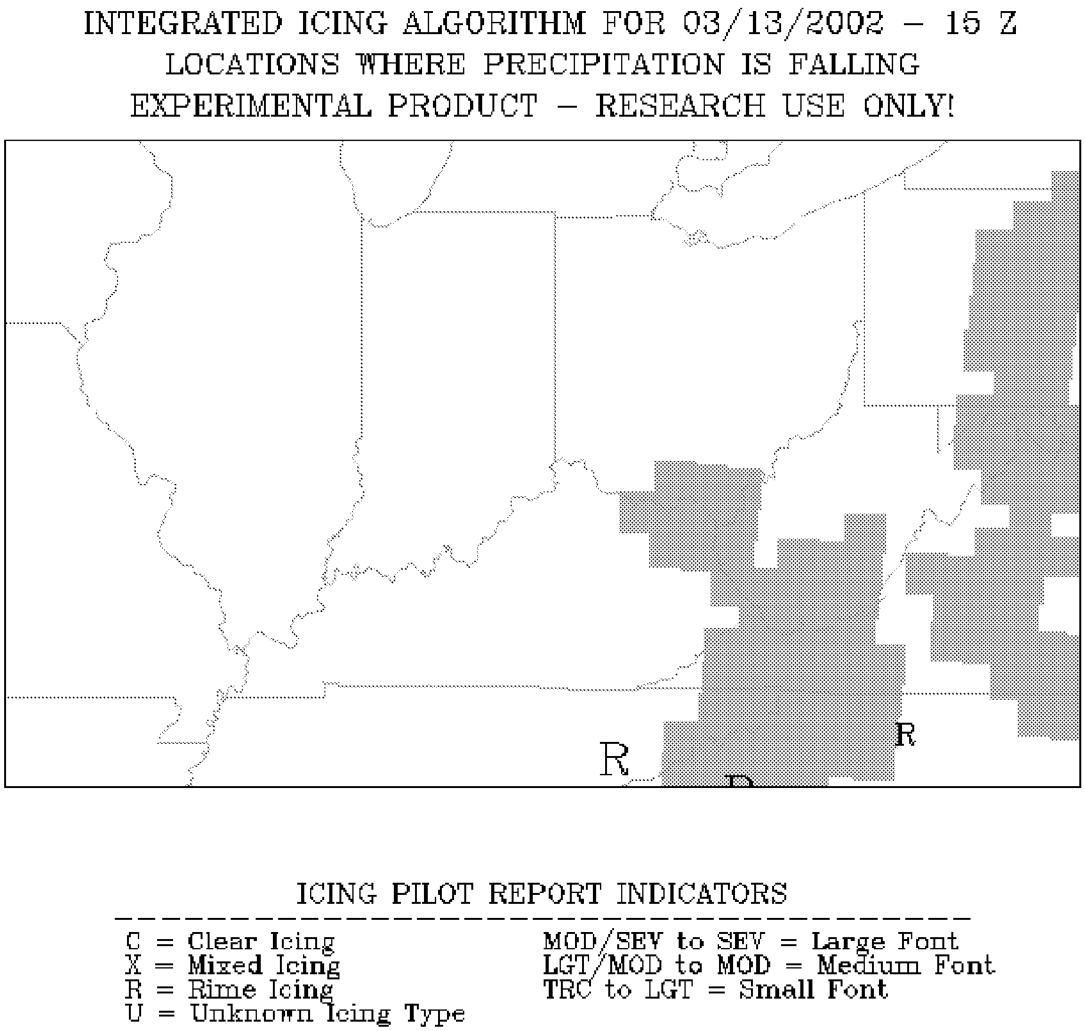

Figure 12. Implemented precipitation

Vertical cross-sections, accessible by selecting the route, were created for a single STAR (HAGSS 2) and a single SID (JOBDU 2) for CVG (Figure 13 and Figure 14). These vertical cross-sections showed IIDA output (icing potential and visible moisture) along the route from surface to 18,000 feet MSL including surface topography. Due to time constraints, SLD was not implemented in the vertical cross-sections.

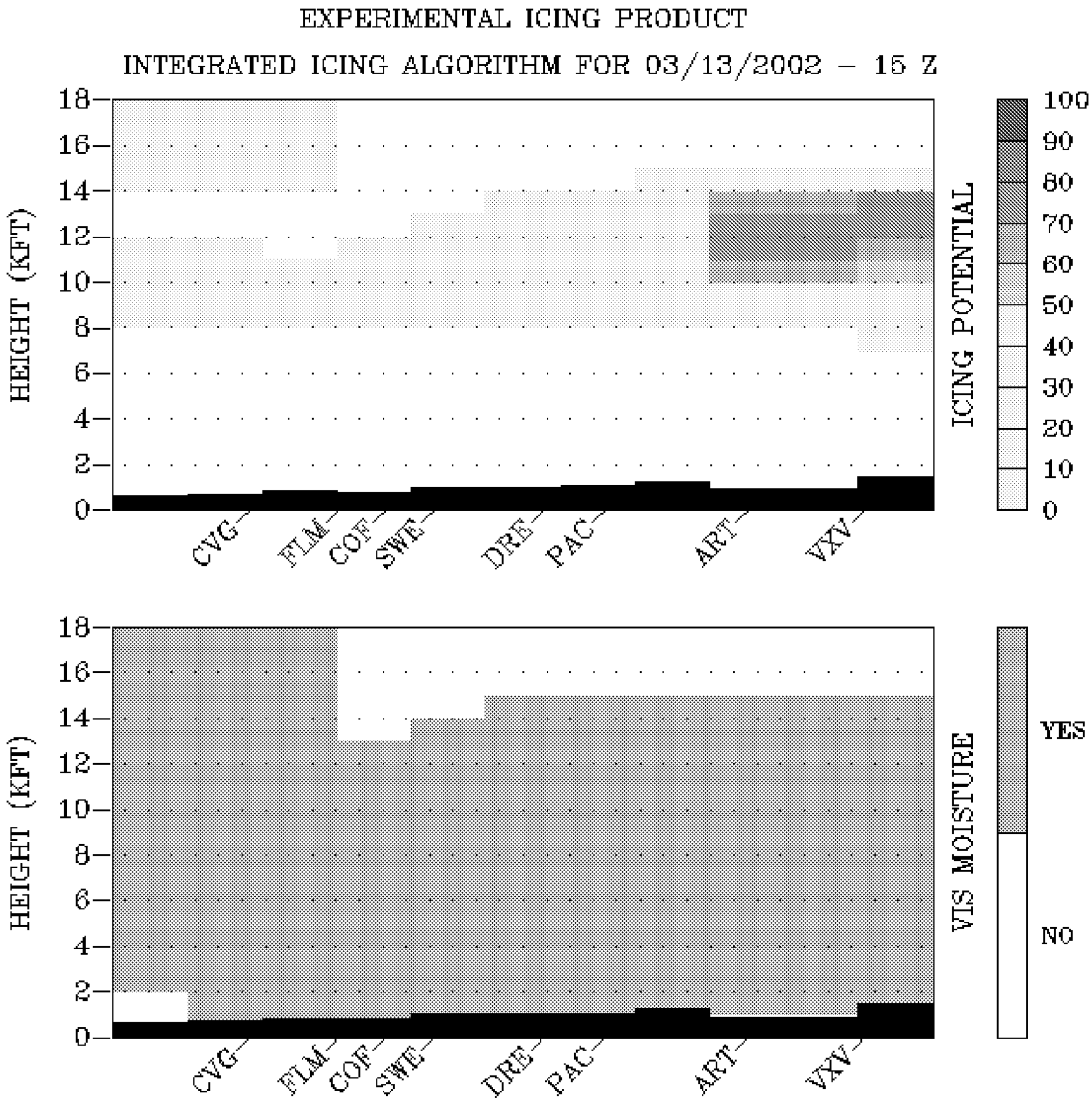

Figure 13. Implemented STAR vertical cross-section

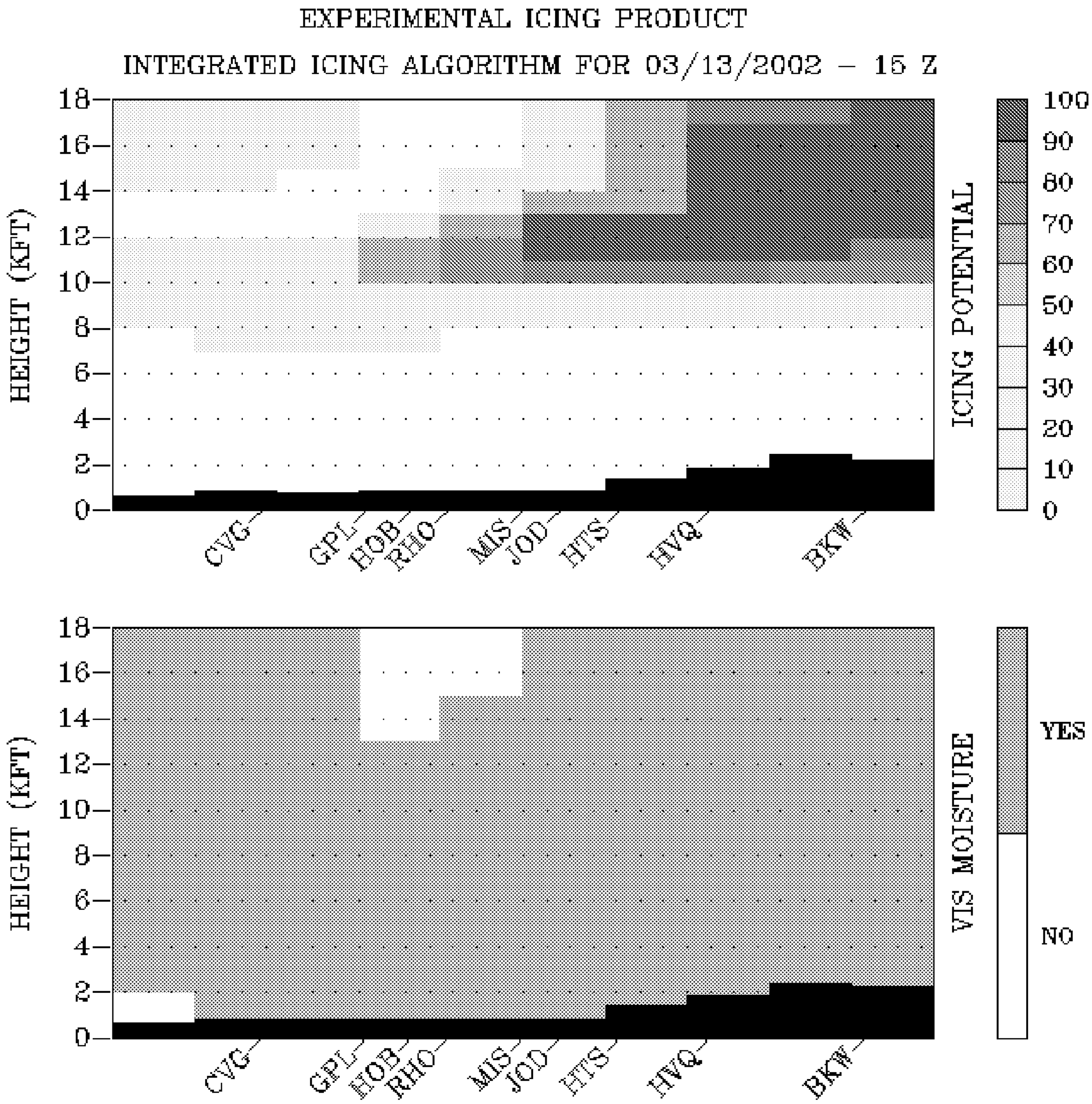

Figure 14. Implemented SID vertical cross-section

Text help is accessible from links on the plan view displays. The text help consists of text explanations on web pages separate from the displays of how to use the displays, what is shown on the displays, concepts associated with IIDA/IIFA, and limitations on their interpretation. The text help is fairly rudimentary (i.e. it is not interactive) and it was not a focus of this study.

Flight Dispatcher Observation/Interview

Three flight dispatchers with different meteorological experience participated in the usability study. The most expert flight dispatcher had previously worked in the meteorology department and conducts meteorology training for the dispatchers. Another had spent a large portion of his career in the weight and balance area and had the least meteorological knowledge. The third dispatcher had an intermediate level of meteorological knowledge.

These dispatchers work about 40 to 45 flight plans per day. Normally, each dispatcher is responsible for about 4 to 5 flights with as many as 8 to 10 in the air at a time. All three dispatchers had a relatively high concentration of flights to/from CVG. They were all observed and interviewed on February 7-8, 2002. The study was conducted while the dispatchers were working the regular shifts. The study was conducted on a non-interfering basis, meaning that operational activities took precedence over usability study concerns.

The procedure for the usability study was as follows:

1. Observe dispatchers without IIDA/IIFA (baseline).
2. Observe dispatchers using IIDA/IIFA without training.
3. Introduce and train dispatchers on IIDA/IIFA.
4. Observe dispatchers using IIDA/IIFA.
5. Debrief.

A complete dispatcher observation plan is included in Appendix C. Dispatcher Observation Plan.

The training conducted in step 3 of the procedure was not extensive: it consisted of a short PowerPoint presentation describing the history of the IIDA/IIFA development and a brief description of IIDA/IIFA concepts. The PowerPoint presentation is available upon request.

Needs for icing information

The flight dispatchers' need for icing information was similar to those interviewed during the display concept phase of the effort. One difference across the flight dispatchers, however, was their "personal minimums" with respect to planning alternates. For example, the most conservative flight dispatcher plans an alternate if the ceiling is forecast to be less than 3500 feet, especially if the prevailing winds appear to favor the movement of the weather system to be at the destination and if wet or slippery runways are indicated at the destination.

Weather Awareness without IIDA/IIFA

The process of accessing information needed for the dispatchers' tasks is laborious. Flight planning and weather awareness require access to many information products, both those that are relevant for icing and weather and those that are not. The flight dispatchers must slowly and methodically request and wade though a great deal of data on multiple displays. The 3 monitors used by the dispatchers were constantly full of overlapping windows. They scan through the text data provided by the company database in their terminal windows. They view graphical weather products in many formats: some integrated with their other decision tools but mostly not. Some of the products are hosted internally, some over the Internet, and some through a text terminal. Moreover, the dispatchers might directly consult a staff meteorologist. For the task of evaluating alternate airports, the dispatchers might consider METARs for the airport, PIREPs near the airport, TAFs, and SIGMETs, among potentially many other products for weather information alone, for example. These individual weather products partially help address this task but in a piecemeal fashion. This laborious process is reflected in the choices the dispatchers have made about accessing products. Different dispatchers have different 'favorite' products that they view frequently while disregarding others: for instance, 'bookmark' lists for Internet weather products are popular for the dispatchers but their contents vary widely among them. The dispatchers have individually placed value on the weather products they use for a variety of reasons: usefulness for their tasks, understandability, resolution of the information, spatial specificity, reliability, and tendency not to overforecast are just a few of these reasons.

Each dispatcher is able to request text weather information, such as METARs, AIRMETs/SIGMETs, by airport (Figure 15). To maintain weather awareness, this text information is automatically sent to the console window when values on such variables as winds and visibility exceed thresholds. Dispatchers can pre-assign a color coding to these messages so that they can be distinguished from other, non-weather related messages.

Each flight dispatcher also has access to many graphic products. Some of the weather products he uses are available internally (e.g. as shown in Figure 16) and some are accessed over the Internet (e.g. Figure 17). To maintain icing awareness, the dispatchers check multiple products such as GOES satellite data, cloud levels, and freezing levels. They monitor the radar data at a low intensity level to look for snow and virga. One dispatcher mentioned that there are difficulties interpreting radar data with respect to icing due to differing reflectivity for different types of precipitation (e.g. light sleet can appear heavy, moderate to heavy snow can appear light). In general, the dispatchers prefer graphic depictions.

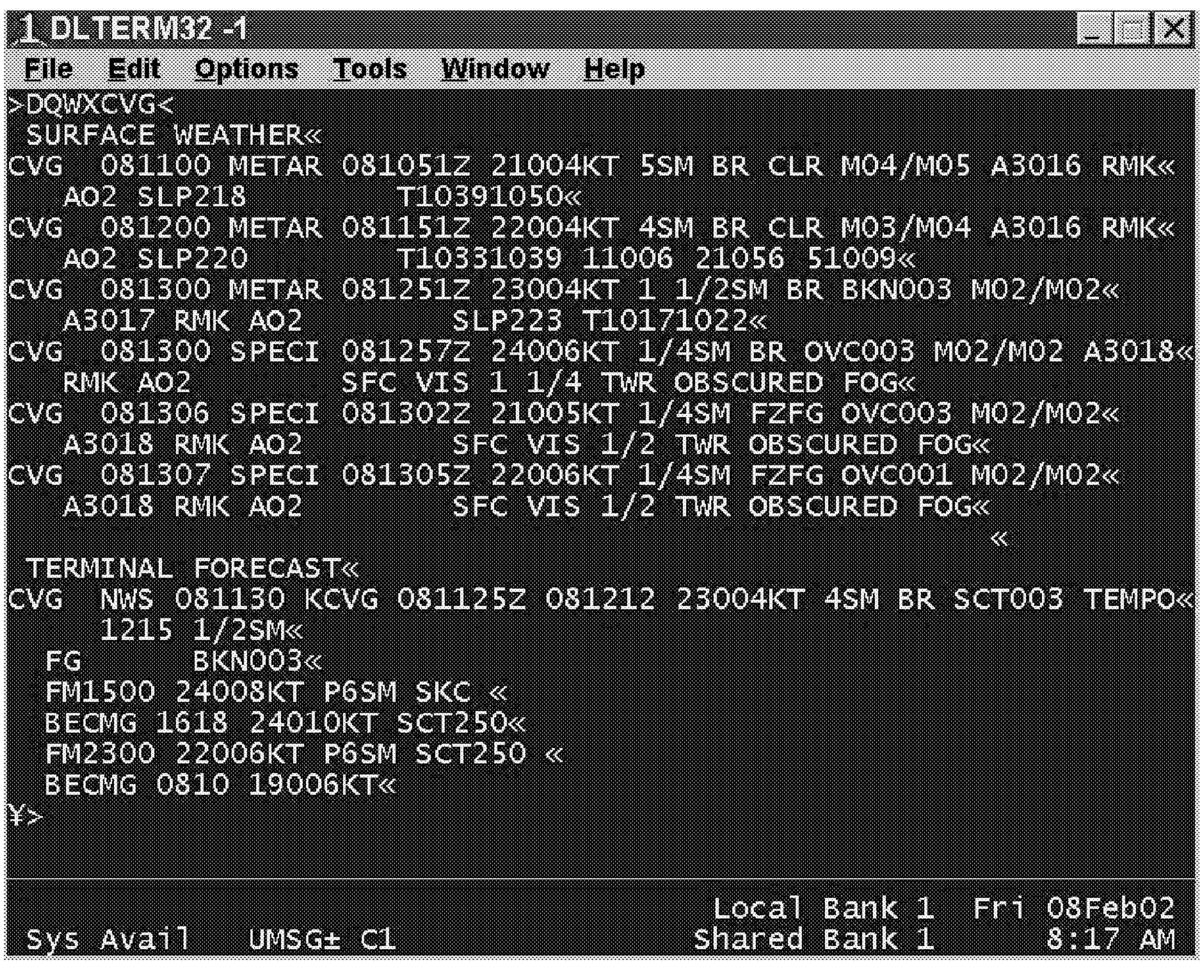

Figure 15. Console window

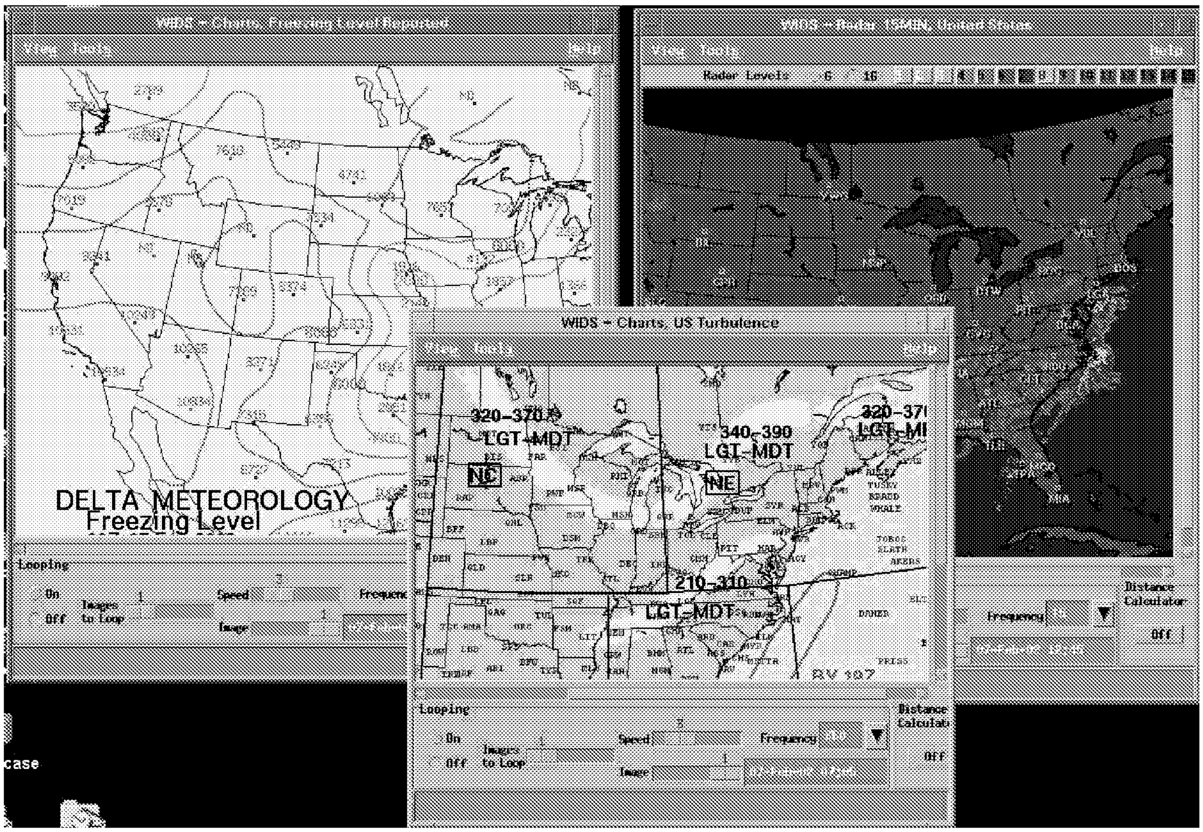

Figure 16. Internal Delta Air Lines weather products

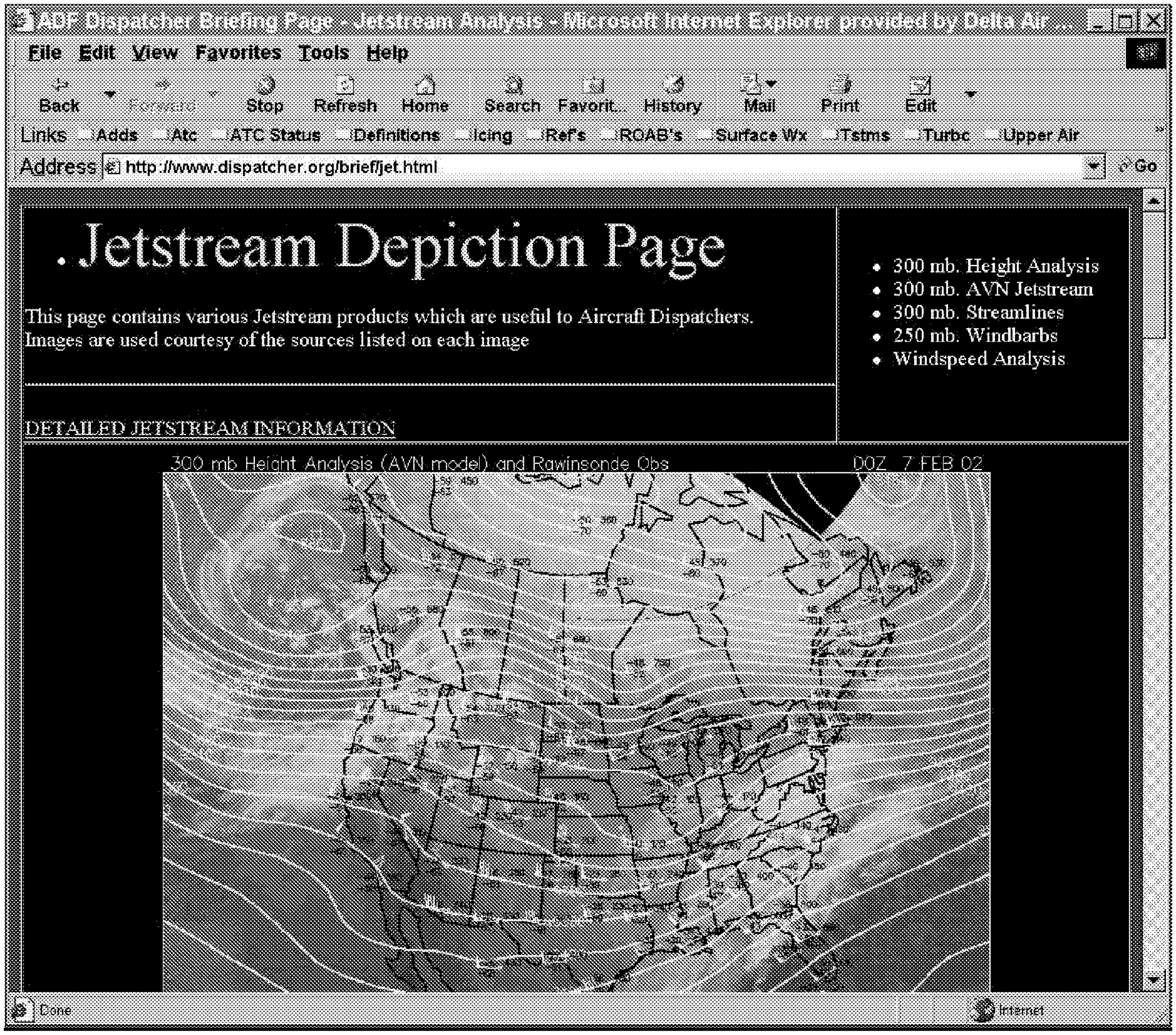

Figure 17. Example weather product linked to the ADF weather briefing page

Understanding IIDA and IIFA

Without training, the flight dispatchers had conceptual difficulty interpreting IIDA and IIFA. One of the issues is particular to IIDA and not IIFA: misunderstanding the diagnostic information as actual occurrence of icing. IIDA does not determine that actual incidence of icing, but represents a 'nowcast', a diagnosis of current conditions. That is, it is an inference of the potential of icing for a given area, not an observation. Flight dispatchers are familiar with forecast data and concepts -- forecasts cannot, by their nature, be an actual determination of conditions since they are a prediction of future conditions – but maybe unfamiliar with the concept of nowcasts. One of the dispatchers without a meteorological background was unable to understand that IIDA represented a nowcast and not the actual, current conditions.

Another potentially problematic issue in interpreting both IIDA and IIFA output is confusing icing potential for icing severity (as also reported by the FAA [2000]). The IIDA/IIFA algorithms calculate a potential for icing, but not the severity of the icing. A feasible concern is that a flight dispatcher might interpret the color coded scale as representing a measure of icing severity, with dark red being the most severe, instead of a measure of the possibility that icing occurrence, regardless of severity. Furthermore, even if it is understood that the IIDA/IIFA scale represents potential of icing and not severity of icing, it is possible that a flight dispatcher might implicitly associate severity with potential. One of the dispatchers without a meteorological background was unsure how to interpret the icing potential scale without instruction. There was no evidence in this study that the flight dispatchers make inferences about icing severity even when they understand that the IIDA/IIFA scale represents icing potential.

An additional issue that emerged during this observational study is that the dispatchers had problems understanding what period of time an IIFA forecast represented. As with other forecast products, an IIFA forecast is relevant relative to the time when the forecast is issued and not the current time. IIFA forecasts are issued every 3 hours based on RUC model data. The dispatchers initially thought the forecasts were based on the current time: when the dispatchers accessed a display with a forecast and saw that the forecast was labeled with a time earlier than expected, they were confused about what time period the forecast actually represented.

When shown the ADDS version of the IIDA, one of the dispatchers commented that he thought he did not really need information about SLD, though it was not clear that he understood the significance of SLD. It is clear that more training with respect to SLD is warranted.

Human-computer interaction and display layout concerns

Navigation to the arrivals and departures display with the boxes labeled “ARRIVALS” and “DEPARTURES” was confusing to the dispatchers. Initially, one of the dispatchers had problems navigating the displays. For instance, he did not understand where to click to get to the vertical cross-sections and he did not realize that he could get to the horizontal cross-sections by clicking in the grid on the bottom left of the terminal-area plan display. He indicated that he initially had problems navigating to the different displays, but that “after playing with it” he no longer had a problem. It is unclear if this still would have been an issue if the SIDs and STARs had been represented on the IIDA/IIFA displays as in the original display concept (i.e. Figure 5). One of the dispatchers also said he would like to be able to see multiple entry and exit points for these routes and to be able to access a vertical cross-section for the whole route from the entry/exit point to the airport by clicking on the entry/exit point on the display.

The dispatchers would like to be able to show more information to help understand where the icing is. Overlays of airways, routes, fixes, and county borders on the IIDA/IIFA plan views might help. More labels for routes and fixes may also help. More data on the vertical cross-sections such as weather stations may also be helpful.

The dispatchers did not initially understand that the text symbols that overlaid the maps in the terminal-area plan view represented PIREPs. The ADDS implementation for PIREPs is preferred. Also, a legend for PIREP symbol meaning and a scale for intensity may be helpful.

The color usage on the displays should be addressed. One dispatcher was unable to distinguish some of the colors on the display due to color blindness. He suggested that dispatchers should be able to set their own color scheme for the icing potential scale. The dispatchers thought that the various coloring used for the text on the displays were confusing. For example, “IFRARED” is in pink and “REGIONAL MOSAIC” is in blue.

The dispatchers had to scroll down frequently during our observation. There is a good deal of white space to the right of the map: perhaps many of the link boxes could be moved to this area.

More suggested functionality

The dispatchers would frequently ask questions about items on the displays or how to navigate the displays. While the help system was not a focus of this study, it is clear that a help system that is more specific to IIDA/IIFA controls and displays is needed. A reasonable next step is to make the help system more context sensitive by associating help text more directly to individual items on the displays or to provide a manual that shows example displays and text associated with items on the displays.

The filtering of icing potential data could be linked to its value. One of the dispatchers commented that he would like to be able to select an icing potential threshold to filter out display of low icing potentials, perhaps using a sliding bar control.

One dispatcher said he would like to see the freezing layer integrated into the IIDA/IIFA displays.

One of the dispatchers said he would like a zoom feature like in the ADDS Java tools. With the zoom feature the user defines a rectangle on a map by clicking on the upper left vertex and dragging to the lower right. The display updates with the area indicated by the rectangle zoomed to fill the display.

The flight dispatchers were concerned about adding yet another product. One of the dispatchers said he would like information about icing as an overlay on the aircraft situation display with an option to toggle on/off. Also he would like to be able to click on a route in the aircraft situation display to view a vertical cross section for that route. The notion of dynamically drawing a vertical cross-section for aircraft under a flight dispatcher's control is worthy of investigation.

The IIDA/IIFA product is currently issued every hour. One dispatcher said that one hour is too long. He said that a fifteen minute time resolution would be good and that a thirty minute time resolution might be sufficient.

One dispatcher said he would like a long range forecast that would support a decision of whether or not an aircraft can leave an airport the next day.

One dispatcher emphasized the importance of not "over-forecasting" (i.e. indicating a high potential for icing in a place where there is actually a low potential. He believes that dispatchers will not use IIDA/IIFA displays if they notice a very few instances of overforecasting.

Summary of Results Obtained

Platform selection

At the major airlines, many aircraft types have ice detector and ACARS capability. Newer aircraft, such as the B777 aircraft, possess integrated information handling systems that can collect data and process downlink reports. Thus without requiring expensive avionics upgrades, icing data from such aircraft could easily be sent to the ground.

To achieve the processing and downlink capability for the B777, the airline would have to modify the Aircraft Condition Monitoring Function software to report the icing information. Maintenance would have to upload the new software on the aircraft. Delta Air Lines estimated that for their seven B-777s, assuming that the requirements for the icing processing are well-defined, the effort resulted in a labor hour estimate of 400 hours and a total project cost of $40,000.00. The details of the schedule and budget are available upon request.

In situ icing data processing

The dissemination of an indication of icing appears to be technically and economically feasible for both CONUS and international weather reports. It has informational value to integrated in flight icing algorithms. Most likely there is little current value to numerical weather prediction (NWP) models. Peak and average liquid water content, together, would be economically feasible for the CONUS. However, costs would double for international reports. Technically, there is some risk in the sensor development and attainable accuracy. These parameters should have value to both integrated in flight icing algorithms and NWP models. Operational humidity sensors have a limited life and may introduce quality control issues. However, humidity (2 characters) might be feasible if reporting frequency is decreased. Water vapor sensors are being installed on a limited number of commercial aircraft. This program may expand to include many aircraft, and is government funded (including communication costs). The exact scope of the program that is approved and funded is unknown at this time. Since communication costs are not paid by the airlines, the block size issue goes away.

The analysis suggests that an icing parameter field should be added to whatever ARINC Specification being used by a particular carrier (for example, ARINC 618). If block size is exceeded (say for an international report), one way to decrease the number of characters needed for any parameter is to use hexadecimal representation of a "bin" or range of values. This technique is being used for downlinking turbulence. Further analysis would be needed to optimize definition of the bin values so that accuracy of the data is not compromised.

Routing of the icing data

The routing mechanism for a new datalink message is quite simple. Basically a new identifier is created and a new entry is added to a routing table. The cost for ARINC to create the identifier and to add it to the routing table is small (perhaps they would even do it at no cost).

Icing case study

The icing case study highlighted the notion that icing conditions generally occur for altitudes well below typical cruise altitudes for the aircraft in a major air carrier's fleet. Thus products tailored for the terminal area may be of great benefit.

Icing display prototype development and evaluation

This effort focused on developing and evaluating a concept for a display that helps major airline flight dispatchers with their icing-related decisions. The display concept included detailed IIDA/IIFA information for the terminal area with a focus on SIDs and STARs. A display prototype for a terminal area around CVG with one SID and one STAR was implemented and evaluated. The three Delta Air Lines flight dispatchers who participated in the evaluation liked the prototype displays and thought they would be useful.

The dispatchers in general liked the terminal area views. Arrivals and departures as well as ground operations are where the DAL dispatchers are most concerned with icing. The evaluation did uncover various usability issues such as usage of color, spatial layout of items, display navigation. The flight dispatchers were concerned about adding another product to their already large assemblage of weather information products, but expressed that the IIDA/IIFA information would be easier to embrace if it were easy to access, preferably integrated with their existing, commonly used tools. This balance between the high value of the information afforded by IIDA/IIFA and a desire for ease of access was expressed in the dispatchers comments about wanting to be able to access the IIDA/IIFA information through their existing, frequently used tools (e.g. overlays on their flight situation display, getting vertical cross-sections by clicking on routes in the flight situation display).

The dispatchers did have some conceptual problems with the displays -- unfamiliarity with the 'nowcast' concept, confusing icing potential for icing severity, confusion concerning IIFA time validity. These problems could be addressed through training and better display design. To help reduce confusion concerning the time validity of IIFA forecasts, IIFA displays should be amended to include the time the forecast was issued. Currently, the IIFA displays are implemented such that each forecast (i.e. 3 hour, 6 hour, 9 hour, 12 hour) for the same area must be accessed separately. An integrated display of all IIFA forecasts for a particular area might also help with the time confusion. Ideally, this integrated display might include an animation of the forecasts. The study also highlighted a lack of icing knowledge such as the importance of SLD. These misconceptions indicate a need for more extensive training.

Future Research

This project should continue down the planned path--that is, equip an aircraft type (B777) to downlink an icing parameter and determine its value to NWP models and integrated algorithms like IIDA and IIFA.

High resolution information on in flight icing hazards has value to both commuter (FAA, 2000) and major air carrier operations. The concept display showing both plan view and vertical cross-sections is useful to the flight dispatcher function, particularly in the terminal area. Easy access to IIDA/IIFA information is a priority for adoption of an icing information tool by the flight dispatchers. IIDA/IIFA can augment the tools commonly used by dispatchers.

Integrating IIDA/IIFA with other tools may allow for more rapid adoption. For example, Delta Air Lines flight dispatchers are currently evaluating a tool they call a "Duty Roster" (Figure 18). The Duty Roster displays various information on the flights being managed: flight status, origin and destination, departure and arrival time, payload, etc. Such data could be used to automatically tailor the IIDA/IIFA display to the terminal areas of concern. Ideally if there may be potential icing hazards, the Duty Roster could be augmented with this information as a prompt to remind the flight dispatcher to view the icing data.

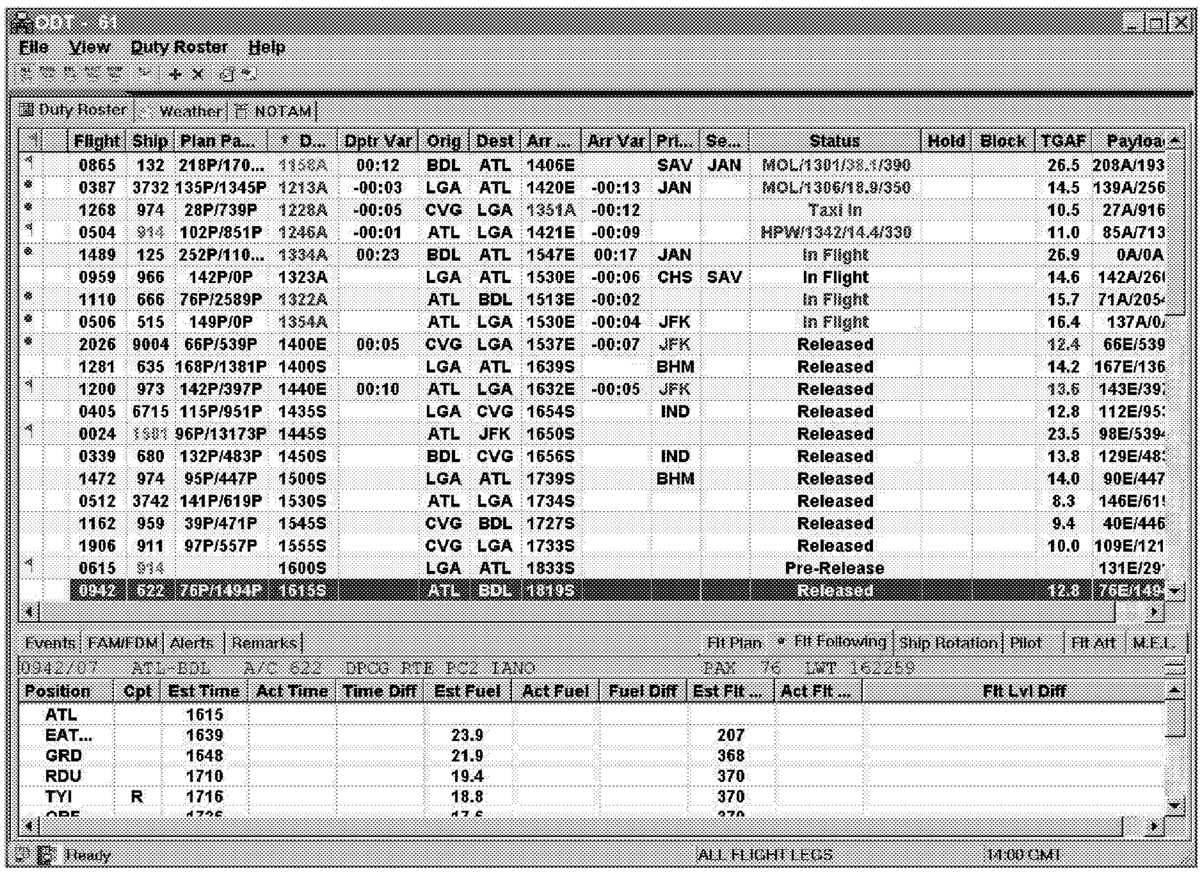

Figure 18. Prototype Duty Roster

While the conceptual problems in understanding IIDA/IIFA displays can be address to some extent with display design, it seems that some of these problems could be addressed with web-based training.

Appendix A. Flight Plan and Weather Briefings

The following is a flight plan and pre-flight weather briefings for ACME airline flight 9999 on March 20, 2000.

Flight plan for ACME 9999 (scheduled 13:55Z – 17:08Z)

```
ATL/DEN  ALTN SLC

SKED                    PLND   ACTL
KATL  1355Z/0855L       1355Z ....
TAXI                    0022  ....
OFF                     1417Z ....
ETE                     0244  ....
ON                      1701Z ....
TAXI                    0007  ....
KDEN  1720Z/1020L 1708Z ....
DOT ON-TIME ARVL LIMIT IS SKED PLUS 14 OR 1734 Z/1034L - APPLIES ONLY TO FLTS
WITHIN 50 STATES / PUERTO RICO / U.S. VIRGIN ISLES

SHIP11111 L/B752/E DGMR TYPE ECN    FL 350 ROUTE NRP 1071 MI
ELEV KATL 1026 FT KDEN 5431 FT

REMARK-   NRP

KATL..WETWO..GAD..MEM..RZC..PER..GCK.J154.RYLIE.DANDD3.KDEN
ETE-244

GAD-MEM  AFTER GAD STEER GAD288 RADIAL UNTIL ABLE TO RCV MEM VOR

RAMP WT 218192 LWT 195076 PAYLOAD 182[1]/041517[2]
MPTW 225422 FLIGHT PLAN    INCLDS CARGO  003479
TARGET GATE ARVL  FUEL     20.6          GATE[3] C42 RAMP XXX
                                                   FREQ 131.45
TRIP TIME/BURN[4] ATL DEN  244/023120 -TAXI[5] 22/00770
IFR/ALTN  SLC  FL350    59/008170
PLND CNTNGNCY FUEL      57/005940 SEE RMKS
UNPLND CNTNGNCY FUEL    15/001560
RESERVE FUEL            005210
BLOCK FUEL              044000
   MIN FUEL FOR T/O     041670

FLIGHT CONTROL AND MAINTENANCE REMARKS
-FUEL
01 ATC/TRFC DLAS ... PSBL LWR FLT LVL ENRTE FOR RIDE
-DISPATCHER
NONE
```

---

1 Passenger count
2 Weight of passengers, baggage, and cargo
3 Scheduled destination gate/ramp
4 Burn includes taxi out and city maneuvering but not taxi in
5 Taxi out time and fuel

-M.E.L. /C.D.L.
S32-00-01 THIS SHIP CARRIES A FLY AWAY KIT IN BIN 1
M25-20-01 PASSENGER CONVENIENCE ITEM/S/

-SHIP REMARKS
11111 ACARS AUTOMATIC ENGINE REPORTING
NOT INSTALLED. PLEASE MANUALLY COMPLETE THE ENGINE PERFORMANCE REPORT SHEET
AS REQUIRED PER FOM PG 7-43.
11111 EEC SWITCH IS LOCATED ON THE P-61 PANEL..ONLY ONE SWITCH FOR BOTH
ENGINES.
11111 HF RADIO EQUIPPED
11111 ASSUMED TEMPERATURE DERATES ARE THE ONLY DERATED TAKEOFFS AUTHORIZED
FOR
THIS AIRCRAFT. TO1 AND TO2 SHOULD NOT BE USED PER 757/767 FLEET SPECIALIST.
11111 NEW MAX TAXI WT 241000 / MAX TAKE OFF WT 240000 EFF.
05DEC98 PER B757 FLEET SPECIALIST
11111 ***PLEASE NOTE COST INDEX - 02DEC99** DOMESTIC ECN-81 /SLI-54 / MNF-0
/
OT1-244 / M83-400 INTL COST INDEX - INTERNATIONAL FLIGHTS SHOULD REFER TO
FOB 99-13 RE FPS FLT PLANS FOR USE OF CI IN HOWGOZIT SECTION.

SUPPLEMENTARY ROUTE INFORMATION
01 ATC PREF--TIME/BURN 246/023300 RTE ATL N0468F350 DCT
WETWO DCT VUZ J41 MEM DCT RZC DCT PER DCT GCK J154 RYLIE DANDD3 DEN
02 --FL 310--TIME/BURN 242/023820

ALERTS[6]	FIX	FL	TEM	PWR	IAS/M	TAS	WCP	GS	ZD	ZT	TRMG ZF	FRMG FAT
											008	
	TAXI										0244	0432
SE1					ECN/CLB		M029		041	010	032	
	WETWO										0234	0400
SE1					ECN/CLB		M067		050	008	018	
	GAD										0226	0382
SE1					ECN/CLB		M068		019	002	005	
	T-O-C										0224	0377
		350	P07	216	272/800	468	M064	404	184	028	036	F302
	MEM										0156	0341
SE1-SC1		350	P05	207	272/800	464	M058	406	215	032	042	F266
R	RZC										0124	0299
SC1		350	P00	199	272/800	461	M052	409	150	022	028	F224
	PER										0102	0271
SC1		350	M02	193	272/801	460	M044	416	184	026	033	F196
	GCK										0036	0238
		350	M02	187	273/801	459	M036	423	058	008	010	F163
	RYLIE										0028	0228
		350	M04	186	273/802	459	M033	426	043	006	008	F153
	T-O-D										0022	0220
					300/802	M003		026	004	000	F145	
	SELLS										0018	0220
									008	001	001	F145
	PRAGG										0017	0219
									013	002	000	F144
	KIPPY										0015	0219
									028	004	002	F144
	DANDD										0011	0217

6 Meteorological alerts

	052	011	008	F142
DEN			0000	0209

[7]DESCENT XPCT 250KIAS AT OR BLO 170

[8]VOR	DVV	DVV	DVV	DVV	DVV	DVV	DVV
RADIAL	118	122	122	122	122	122	122
DME	118	090	078	065	053	050	044
FL	350	310	270	230	190	180	170

[9]COMPUTED ENROUTE WINDS

FIX	TROP	CRZ FL	TWO FLT LVLS LOWER		TWO FLT LVLS HIGHER	
		SAT TAT	SAT TAT	SAT TAT	SAT TAT	SAT TAT
T-O-C	33	35 27067[10]	31 27074	33 27071	37 27061	39 W[11]27054
MEM	34	35 29063	31 29072	33 29068	37 29057	39 W28052
		-47 -18	-45 -16	-47 -18	-48 -19	-48 -19
RZC	36	35 29054	31 29050	33 29053	37 29054	39 28053
		-53 -25	-48 -19	-51 -23	-54 -26	-54 -26
PER	38	35 27052	31 26043	33 27047	37 27055	39 26057
		-56 -28	-49 -20	-53 -25	-58 -31	-58 -31
GCK	39	35 24066	31 24058	33 24063	37 24067	39 24064
		-57 -30	-48 -19	-53 -25	-60 -33	-61 -34
RYLIE	38	35 23072	31 23064	33 23068	37 23072	39 23069
		-58 -31	-48 -19	-54 -26	-60 -33	-61 -34
T-O-D	38	35 23075	31 22066	33 22071	37 23076	39 23073

FIX LIST DATA

FIX	FMS	LAT	LONG	AVG T/C	AVG VAR	D/C	AVG M/H
KATL		N33 38.4	W084 25.6	279	W02		
WETWO		N33 43.7	W085 07.4	287	W01		
GAD		N33 58.6	W086 05.0	288	E01		
MEM		N35 00.9	W089 59.0	290	E04		286
RZC		N36 14.8	W094 07.3	282	E06	R01	277
PER		N36 44.8	W097 09.6	293	E08	L03	282
GCK		N37 55.1	W100 43.5	296	E11	L07	278
RYLIE		N38 20.2	W101 49.7	295	E12	L08	275
SELLS		N38 49.6	W103 10.1	314	E12		
PRAGG		N38 55.0	W103 17.4	314	E12		
KIPPY		N39 04.3	W103 29.8	314	E12		
DANDD		N39 23.9	W103 56.3	309	E12		
KDEN		N39 51.5	W104 40.0				

AIRPORT/NAVIGATIONAL REMARKS

-AIRPORT PAIR REMARKS
ATL-DEN **THIS IS A CITY PAIR IN WHICH WE ARE ALLOWED TO USE ANY ROUTE WHICH COMPLIES WITH NRP RULES..MUST INCLUDE AF/--NRP REMARK ON FLT PLAN..PREF RTE IS OPL//CB FLTCTL//29NOV99CL

---

7 Crossing restrictions
8 4000 foot descent checkpoints
9 Calculated for fix positions and planned fix crossings
10 First two digits are direction in tens of degrees; last three digits are velocity
11 W prefix indicates aircraft is too heavy for that altitude

```
-AIRPORT REMARKS
SLC   02
   BEARR THREE ARRIVAL - AT BEARR INT ACFT LNDG SOUTH EXPECT
   CLEARANCE TO CROSS AT 16000 FT.  ÄCHART NOTAM)
SLC   03
   BRIGHAM CITY ONE ARRIVAL - AT CARTR INT ACFT LNDG SOUTH
   EXPECT CLEARANCE TO CROSS AT 15000 FT.  ÄCHART NOTAM)
SLC   06
   PARKING GATES D2 AND D6 USE 2L DOOR.
   SLCCPO/28FEB00

-AIRPORT NOTAMS
ATL   02/025 8L ILS DME CMSND WEF 0002240901
ATL   03/009 TOWER 1220  250 AGL  4.8 NE LGTS OTS TIL  0003210900
ATL   03/012 TOWER 1150  250 AGL  4.1 SE LGTS OTS TIL  0003250700
ATL   03/023 9R ILS CAT 2/3 NA WEF 0003151300
ATL   03/027 TOWER 1117  148 AGL  2.9 SE LGTS OTS TIL  0003292000
ATL   03/030 TOWER 1420  400 AGL  5.9 NE LGTS OTS TIL  0003310500
DEN   03/058 16/34 RWY LGTS OTS
DEN   03/077 TOWER UKN  400 AGL  5 NW LGTS OTS TIL 0003300530
SLC   02/064 TOWER 5458  249 AGL  9E LGTS OTS
SLC   03/050 TACAN AZM OTS
SLC   03/053 14/32 CLSD
SLC   03/052 ALL RWYS ALTNLY CLSD SNOW REMOVAL

-JEPPESEN CHANGES/FDC NOTAMS/INTERNATIONAL NOTAMS
ATL   0/0940
   VOR OR GPS RWY 27L  AMDT 4...
      TERMINAL ROUTE FROM PANOL INT/ATL 10.1 DME IAF TO AMATE
      INT/   ATL 4.80 DME NOPT DELETE IAF AND NOPT.  ADD
      FROM AMATE INT TO RWY 27L  2.94 DEGREES/ TCH 65 FT.
   THIS IS VOR OR GPS RWY 27L   AMDT 4A.
ATL   0/0944
   ILS RWY 27R  AMDT 3A...
      TERMINAL ROUTE FROM HOKIE INT/ATL 10.32 DME/ RADAR
      IAF TO LIAMS OM/INT/ ATL 6.30 DME/RADAR NOPT DELETE
      IAF AND NOPT.
   THIS IS ILS RWY 27R  AMDT 3B.
ATL   0/0946
   ILS RWY 26L  AMDT 17B...
      TERMINAL ROUTE FROM KINKY INT IAF TO PANOL INT  NOPT
      DELETE  IAF AND NOPT.
   THIS IS ILS RWY 26L  AMDT 17C.
ATL   0/0950
   ILS RWY 8R CAT II  AMDT 58A...
      TERMINAL ROUTE FROM CHINN INT/ATL 13.70 DME IAF TO
      STUMP INT/  ATL 9.90 DME NOPT DELETE IAF AND NOPT.
   THIS IS ILS RWY 8R  CAT II  AMDT 58B.
ATL   0/0953
   ILS RWY 9R  CAT II III  AMDT 16...
      TERMINAL ROUTE FROM TIZZY INT/I-FUN 10.70 DME IAF TO
      BURNY INT/OM/I-FUN 6.4 DME NOPT DELETE IAF AND NOPT.
   THIS IS ILS RWY 9R CAT II III  AMDT 16A.
ATL   0/0941
   ILS RWY 27L  AMDT 13...
   TERMINAL FROM ANVAL INT/I-FSQ 10.64 DME/RA
 DAR IAF TO DEPOT
```

```
   INT  NOPT DELETE IAF AND NOPT.
   THIS IS ILS RWY 27L  AMDT 13A.
ATL   0/1465
   ILS RWY 26R  AMDT 2A...
   TERMINAL ROUTE FROM FREAL INT  IAF  TO BALLI INT  NOPT
   DELETE IAF AND NOPT.
   THIS IS ILS RWY 26R  AMDT 2B.
DEN I 9/6089
    ILS RWY 25 AMDT 1..
    S-ILS DH 5668/HAT 316 RVR 4000 ALL CATS
    S-LOC MDA 5760/HAT 408 RVR 4000 ALL CATS FOR INOP MALSR
    TEMP CRANES..3..5455FT MSL 3704FT FROM RWY 25 THLD..954FT
   LEFT OF CTRLINE.

-ENROUTE NOTAMS
MSL     001 09/003 TACAN AZM OTS
AMG     001 03/003 VOR UNUSBL 330-078/095-116/141-149/169-193/210-215
        BYD 10 BLW 5000/ 079-094/117-140/150-168/194-209/216-225/235-329
        BYD 10 BLW 9000 PLUS SEE AFD
FSM     001 03/017 VOR OTS WEF 0003201400-0003202200
IRW     001 EXPECT RADAR VECTORS FROM ATC DURING VOR OUTAGE//FEB02//FLTCTRL
RLG     001
   DEN 11/148 TACAN AZM OTS
SNY     001 03/005 VORTAC OTS WEF 0003201600-0003202000
SLC     001 03/050 TACAN AZM OTS

ACME 9999/20 RLS 1 ATL-DEN  20MAR1245RP
```

Final weather briefing for ACME 9999 (12:48Z)

```
FL 350         ETE 0244         20MAR1248
ATL 1355Z 0855L-DEN 1720Z 1020L ALTN SLC
ATL..WETWO..GAD..MEM..RZC..PER..GCK.J154.RYLIE.DANDD3.DEN

              DESTINATION WEATHER
DEN 201000 METAR 200953Z 02016KT 10SM SCT060 BKN120 BKN250
    03/M01 A2952   RMK AO2 SLP956 T00331011
DEN 201100 METAR 201053Z 36017KT 10SM SCT050 BKN110 BKN250
    00/M02 A2959   RMK AO2 PK WND 01030/1030 PRESRR SLP989 T00001022
DEN 201200 METAR 201153Z 35019KT 10SM BKN014 OVC100 M01/M03
    A2965 RMK AO2   PRESRR SLP015 T10061028 10106 21006 53044

              DESTINATION FORECAST
 TERMINAL FORECAST
DEN  NWS 201142 KDEN 201138Z 201212 35015G28KT P6SM BKN015
      TEMPO 1215 4SM -SHRASN
   FM1500 36012G22KT 5SM -SHRASN BKN008 TEMPO 1518 2SM -SHSN BR OVC005
   FM1800 02015G28KT 2SM -SN BR BKN003 OVC010 TEMPO 1821 3/4SM SN BR VV002
   FM2100 03017G30KT 1SM SN BLSN OVC003 TEMPO 2103 1/4SM SN BLSN VV001
   FM0300 05016G35KT 1/2SM SN BLSN OVC003

              WEATHER AROUND DESTINATION
COS 201200 METAR 201154Z 01010KT 10SM FEW060 02/M06 A2952 RMK
    AO2 SLP968  T00171056 10106 20011 55006
CYS 201200 METAR 201156Z 36023G28KT 1SM -SN BR BKN015 OVC036
    M05/M06   A2965 RMK AO2 PK WND 35030/1122 SLP033 P0002
    60006 T10501061  10072 21050 51017
CYS 201200 METAR 201156Z COR 36023G28KT 1SM -SN BR BKN015
    OVC036 M05/M06   A2965 RMK AO2 PK WND 35030/1122
    SLP033 P0002 60006 70006   T10501061 10072 21050 51017
CYS 201222 SPECI 201219Z 35023G31KT 1SM -SN BR BKN013 BKN022
    OVC036   M06/M07 A2966 RMK AO2 PK WND 35031/1219 P0000
CYS 201228 SPECI 201225Z 36024G31KT 3/4SM -SN BR SCT013 BKN022
    OVC036   M06/M07 A2965 RMK AO2 PK WND 36031/1225 P0000
PUB 201200 METAR 201154Z 00000KT 10SM CLR 05/M03 A2947 RMK AO2
    SLP943   T00501033 10050 21006 55014
GJT 201200 METAR 201156Z 28006KT 3/4SM -SN BR BKN004 OVC009
    00/M01 A2960   RMK AO2 SLP005 P0012 60012 70012
    T00001006 10133 20000   53018
GJT 201200 METAR 201156Z 28006KT 3/4SM -SN BR BKN004 OVC009
    00/M01 A2960   RMK AO2 SLP005 P0012 60012 70012
    T00001006 10133 20000   53018
CPR 201200 METAR 201155Z 03008KT 1 1/2SM -SN BR OVC017 M04/M06
    A2983 RMK   AO2 SLP106 P0002 60013 70022 T10391056
    11033 21044 53016

              ALTERNATE AIRPORT WEATHER
SLC 201000 METAR 200956Z 09003KT 10SM SCT034 OVC110 M03/M04
    A2979 RMK   AO2 SNE09 SLP086 SNINCR 1/2 P0000 T10331039
SLC 201100 METAR 201056Z 00000KT 10SM FEW045 BKN060 BKN080
    M03/M04 A2979   RMK AO2 SLP100 T10281039
SLC 201200 METAR 201156Z 34007KT 10SM FEW035 BKN080 M05/M06
```

```
    A2979 RMK   AO2 SLP104 60019 70034 4/003 T10501061 11017 21067 56007

                 ALTERNATE FORECAST
 TERMINAL FORECAST
SLC  DL  201118 AMD 02 VALID 201118-210300 UTC
   15 BKN 40 OVC 10 3510 OCNL 2SW-
   15Z 15 BKN 40 OVC 10 3515G25 OCNL 2SW-
   20Z 25 SCT 70 BKN 10 3618G28
   02Z 30 SCT 150 BKN 10 3614
   // NO ADNL ACCUMN SNOW //

              ORIGIN WEATHER
ATL 201100 METAR 201053Z 22003KT 10SM FEW007 SCT017 BKN045
    11/10 A2986   RMK AO2 SLP113 T01060100
ATL 201200 METAR 201153Z 24006KT 9SM SCT009 BKN012 BKN038 11/10
    A2989   RMK AO2 SLP120 60002 70159 T01060100 10122
    20100 53020
ATL 201245 SPECI 201241Z 27007KT 10SM FEW008 BKN026 BKN041
    11/09 A2991   RMK AO2 VIRGA SW AND NW

              ORIGIN FORECAST
 TERMINAL FORECAST
ATL  DL  201107 AMD 01 VALID 201107-210300 UTC
   10 OVC 7 2405
   14Z 15 BKN 7 2610
   16Z 25 BKN 7 2712
   18Z 35 BKN 10 2812
   20Z 45 SCT 10 2810
   22Z CLR 10 3008

TAKEOFF ALTERNATE WEATHER
NO REPORT

              ENROUTE SURFACE WEATHER
ATL 201200 METAR 201153Z 24006KT 9SM SCT009 BKN012 BKN038 11/10 A2989
    RMK AO2 SLP120 60002 70159 T01060100 10122 20100 53020
ATL 201245 SPECI 201241Z 27007KT 10SM FEW008 BKN026 BKN041
    11/09 A2991   RMK AO2 VIRGA SW AND NW
MEM 201200 METAR 201153Z 26005KT 10SM SCT021 OVC034 07/04 A2991
    RMK AO2   CIG 024 RWY27 SLP129 70092 T00720044 10072 20067 53019
MEM 201219 SPECI 201218Z VRB05KT 10SM FEW020 BKN026 OVC033 07/04 A2992 RMK
AO2
TUL 201200 METAR 201153Z 14003KT 6SM BR CLR 00/00 A2991 RMK AO2
    SLP128   T00000000 10028 21006 53008
OKC 201200 METAR 201153Z 12012KT 10SM CLR 04/01 A2979 RMK AO2
    SLP087   T00440011 10056 20039 56005

METRO ALERTS
SE1 200754-202100               ***** SOUTHEAST REGION *****
OVER ERN GA/SC/NC/FL
    AREA WDLY SCT TRW PSBL....TOPS FL380
    MOVG NE 20KT
SC1 200755-202100            ***** SOUTH CENTRAL REGION *****
***** NO MDT OR GRTR TURBC OR TRW FORECAST *****

               GOVERNMENT WEATHER ALERTS
Z22 201154-201355 CONVECTIVE SIGMET 15E VALID UNTIL 1355Z NC SC GA FROM 30NW
```

```
    CLT-20SE CAE-40WNW SAV LINE SEV TS 15 NM WIDE MOV FROM 25030KT. TOPS TO
    FL400. HAIL TO 1 IN...WIND GUSTS TO 50 KT POSS.
Z24 201154-201355 CONVECTIVE SIGMET 16E VALID UNTIL 1355Z SC GA AND CSTL WTRS
    FROM 30W CHS-60SSE CHS-50S SAV-30W CHS DVLPG AREA TS MOV FROM 23030KT.
TOPS
    TO FL320.  OUTLOOK VALID 201355-201755 FROM ORF-170E PBI-70ENE PBI-130SE
    MIA-80WSW EYW-90W SRQ-CAE-HMV-ORF TS WILL CONT ALG/EAST OF CDFNT MOVG EWD
    ACRS THE AREA. ACT SHOULD BE MAINLY OVER THE CAROLINAS AND ADJ WATERS
WITH
    WDLY SCT TS POSSIBLE IN MODERATELY UNSTABLE AMS OVER FL AND COASTAL
WATERS.
    OCNL WST ISSUANCES ARE LIKELY.

ACME PIREPS
ACME0251/19 SHIP 0689 POS RZC  OVR 0949 NXT CIM
      ETA 1106    ENS PGS ALT 310 FOB 0371 SAT 49 WND 287069 MCH 80 TRB LT
      CHOP SKY CLEAR ICE NONE
ACME1448/19 SHIP 0665 POS RZC  OVR 0956 NXT CIM
      ETA 1114    ENS PGS ALT 310 FOB 0383 SAT 48 WND 286066 MCH 80 TRB
      SMOOTH SKY CLEAR ICE NONE
ACME0198/19 SHIP 0608 POS SGF  OVR 0953 NXT
      ETA         ENS   ALT 370 FOB 0203 SAT 53 WND 275043 MCH 80 TRB SMOOTH
      SKY CLEAR ICE NONE
ACME0548/19 SHIP 0127 POS PER  OVR 1002 NXT KCVG
      ETA 1125    ENS ALT 370 FOB 0346 SAT 59 WND 281029 MCH 80 TRB SMOOTH
      SKY CLEAR ICE NONE
ACME1244/20 SHIP 0611 POS GCK  OVR 1029 NXT ENL
      ETA 1133    ENS KCVG ALT 330 FOB 0307 SAT 52 WND 263050 MCH 80 TRB
      SMOOTH SKY CLEAR ICE NONE
ACME0384/19 SHIP 0639 POS LBL  OVR 1020 NXT
      ETA         ENS   ALT 330 FOB 0317 SAT 52 WND 273045 MCH 80 TRB LT CHOP
      SKY CLEAR ICE NONE

              SUBSEQUENT STATIONS
NONE

              AIRPORT ALERTS
ATL NO REPORT
DEN NO REPORT
SLC 201245-210600  MDT TURBC DURGC/DURGD SFC-FL100

              FIELD CONDITIONS
ATL NO REPORT
DEN NO REPORT
SLC NO REPORT
```

Updated weather briefing for ACME 9999 (13:48Z)

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FL 350          ETE 0244         20MAR1358
ATL 1355Z 0855L-DEN 1720Z 1020L ALTN SLC
ATL..WETWO..GAD..MEM..RZC..PER..GCK.J154.RYLIE.DANDD3.DEN

              DESTINATION WEATHER
DEN 201300 METAR 201253Z 36013KT 10SM BKN012 OVC110 M01/M03
    A2968 RMK AO2   SLP036 T10111033
DEN 201400 METAR 201353Z 34024G27KT 10SM OVC012 M01/M04 A2972
    RMK AO2 PK      WND 33027/1353 SLP054 SHSN VC SW-W
    T10111044

DESTINATION FORECAST
 TERMINAL FORECAST
DEN  NWS 201333 AMD KDEN 201320Z 201312 35012G20KT P6SM BKN012
      TEMPO 1416   4SM  -SHSN
   FM1600 01013G22KT 5SM -SHSN BKN008 TEMPO 1618 2SM -SHSN BR OVC005
   FM1800 02015G25KT 2SM -SN BR BKN003 TEMPO 1923 3/4SM SN BR VV002
   FM2200 04017G30KT 1SM SN BLSN OVC003 TEMPO 2304 1/4SM SN BLSN VV001
   FM0400 05014G25KT 1/2SM SN BLSN OVC003

              WEATHER AROUND DESTINATION
COS 201300 METAR 201254Z 36025G35KT 10SM FEW005 SCT060 SCT110 01/M02 A2955
      RMK AO2 PK WND 36035/1252 SLP991 T00061022
CYS 201300 METAR 201256Z 35015G22KT 1SM -SN BR BKN011 OVC036 M06/M07   A2970
      RMK AO2 PK WND 36031/1225 SLP058 P0000 T10561067
CYS 201322 SPECI 201310Z 36017G22KT 3/4SM -SN BR VV009 M06/M07 A2971
      RMK   AO2 TWR VIS 1 P0000
CYS 201332 SPECI 201330Z 36015G24KT 1/4SM PSN FZFG VV005 M06/M07 A2972
      RMK AO2 TWR VIS 1 P0000
PUB 201300 METAR 201254Z 02004KT 10SM CLR 01/M03 A2949 RMK AO2 SLP960
T00111028
GJT 201300 METAR 201256Z 27007KT 3/4SM -SN BR OVC003 M01/M01 A2960
      RMK   AO2 SLP009 P0006 T10061006
GJT 201308 SPECI 201305Z 27008KT 1 1/4SM -SN BR OVC003 M01/M01  A2959
      RMK AO2 P0001
GJT 201322 SPECI 201305Z 27008KT 1 1/4SM -SN BR OVC003 M01/M01 A2959
      RMK   AO2 P0001
CPR 201300 METAR 201255Z 02014G18KT 1 3/4SM -SN BR FEW016 OVC021 M04/M06
A2985
      RMK AO2 SLP117 P0001 T10441061
CPR 201309 SPECI 201305Z 03016KT 2 1/2SM -SN BR FEW014 OVC023 M04/M06 A2986
      RMK AO2 P0000
CPR 201326 SPECI 201316Z 03014KT 2 1/2SM -SN BR OVC035 M04/M06 A2986
      RMK   AO2 P0000
CPR 201349 SPECI 201346Z 03013KT 3SM -SN BR FEW018 OVC033 M04/M06 A2988
      RMK AO2 P0000

               ALTERNATE AIRPORT WEATHER

SLC 201300 METAR 201256Z 33005KT 10SM FEW020 SCT060 BKN080 M04/M05 A2981
      RMK AO2 SLP110 T10391050
```

ORIGIN WEATHER

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ATL 201300 METAR 201253Z 27007KT 10SM FEW008 BKN026 BKN041 11/08 A2992
      RMK AO2 SLP131 VIRGA SW AND NW T01060083
ATL 201400 METAR 201353Z 29006KT 10SM FEW012 SCT040 11/08 A2993
      RMK AO2  SLP135 MDT CU DSNT NE T01110083
```

ENROUTE SURFACE WEATHER

```
ATL 201400 METAR 201353Z 29006KT 10 SM FEW012 SCT040 11/08 A2993
      RMK AO2   SLP135 MDT CU DSNT NE T01110083
MEM 201400 METAR 201353Z 26006KT 10SM FEW020 OVC033 07/04 A2996
      RMK AO2   SLP144 T00720039
TUL 201300 METAR 201253Z 00000KT 4SM BR CLR 00/00 A2991
      RMK AO2 SLP130 T00000000
OKC 201400 METAR 201353Z 14016KT 10SM CLR 07/02 A2978
      RMK AO2 SLP085   T00670022
```

GOVERNMENT WEATHER ALERTS

```
Z28 201251-201455 CONVECTIVE SIGMET 17E VALID UNTIL 1455Z SC AND CSTL WTRS
   FROM 40SE CLT-20NNW CHS-50SE SAV LINE TS 25 NM WIDE MOV FROM 24035KT. TOPS
   TO FL380.  OUTLOOK VALID 201455-201855 FROM ORF-170E PBI-70ENE PBI-130SE
   MIA-80WSW EYW-100WSW SRQ-CAE-30NE HMV-ORF TS WILL CONT ALG/EAST OF CDFNT
   MOVG EWD ACRS THE AREA. ACT SHOULD BE MAINLY OVER THE CAROLINAS AND ADJ
   WATERS. WDLY SCT TS POSSIBLE IN MODERATELY UNSTABLE AMS OVER FL AND
   COASTAL WATERS. OCNL WST ISSUANCES ARE LIKELY.
Z35 201349-201555 CONVECTIVE SIGMET 18E VALID UNTIL 1555Z SC AND CSTL WTRS
   FROM 40NNE CAE-20E FLO-110SSE CHS-30SE SAV-40NNE CAE AREA TS MOV FROM
   25030KT. TOPS TO FL410. OUTLOOK VALID 201555-201955 FROM ORF-170E PBI-
   70ENE PBI-130SE MIA-80WSW EYW-100WSW SRQ-CAE-30NE HMV-ORF TS CONTG ALG/
   EAST OF CDFNT MOVG THRU SRN ATLC CST STATES. MOST ACTV CNVTN EXPD TO BE
   MNLY OVER THE CAROLINAS AND ADJ WATERS. WDLY SCT TS POSS THIS AFTN IN
   MODLY UNSTABLE AMS OVER FL AND CSTL WTRS. OCNL WST ISSUANCES ARE LIKELY
   THRU MUCH OF PD.
```

Appendix B. Airports and Navigation Aids

This appendix lists the airports and navigation aids appearing in the case study information. The format of each entry is the identifier, the longitude, the latitude, and the English name.

Airports

ATL, -84.426944, 33.640444, “Atlanta”
COS, -104.70025, 38.805806, “Colorado Springs”
CPR, -106.464466, 42.908356, “Casper”
CYS, -104.811838, 41.155723, “Cheyenne”
DEN, -104.667, 39.85841, “Denver”
GJT,-108.526735, 39.12241, “Grand Junction”
MEM , -89.976667, 35.042417, “Memphis”
OKC, -97.600734, 35.393088, “Oklahoma City”
PUB, -104.496572, 38.289087 , “Pueblo”
SLC, -111.977773, 40.788388, “Salt Lake City”
TUL, -95.888242 , 36.198372 , “Tulsa”

Navigation Aid

AKO, -103.179740, 40.155578, “Akron”
ALS, -105.815535, 37.349159, “Alamosa”
BFF, -103.482022,41.894159, “Scottsbluff”
BOY, -108.299712, 43.463152, “Boysen Reservoir”
BTY, -116.747647, 36.800584, “Beatty”
BZA, -114.60284, 32.768129, “Bard”
CAE, -81.053904, 33.857249 , “Columbia”
CHE -107.304893, 40.520084, “Hayden”
CHS, -80.037811, 32.894313, “Charleston”
CLT, -80.95175, 35.190289, “Charlotte”
DIK, -102.773502, 46.859984, “Dickinson”
DPR, -101.715071, 45.078175, “Dupree”
DRK, -112.480349, 34.702556, “Drake”
DVC, -108.931274, 37.80874, “Dove Creek”
EED, -114.474104, 34.766004, “Needles”
ELY, -91.830147, 47.821852, “Ely”
EYW , -81.800476, 24.585878, “Key West”
FMG, -119.656074, 39.531273, “Mustang”
FMN, -108.098899, 36.748393, “Farmington”
GCK, -100.725084 , 37.919067,“Garden City”
GEG, -117.626889, 47.564944, “Spokane”
GLD, -101.692306, 39.387861, “Goodland”
HBU, -107.039792, 38.452153, “Blue Mesa”
HLC, -100.22585, 39.258747, “Hill City”
HMV, -82.129573, 36.437054, “Holston Mountain”
ILC, -114.394226, 38.250193, “Wilson Creek”
INW, 110.795027, 35.061602, “Winslow
JNC, -108.792574, 39.059566, “Grand Junction”
LAA, -102.687532, 38.197092, “Lamar”
LAR, -105.720937, 41.337864, “Laramie”
LBL, -100.9712, 37.0444, “Liberal”

MIA, -80.278889 , 25.794722, “Miami”
OCS, -109.015313 , 41.590214 ,”Rock Springs”
ORF, -76.20033, 36.891897, “Norfolk”
PBI, -80.0865, 26.680052, “Palm Beach”
PIR, -100.162877, 44.394511, “Pierre”
PUB , -104.429442, 38.294252, “Pueblo”
SAV, -81.112505, 32.160554, “Savannah”
SGF, -93.334052 , 37.355961, “Springfield”
SHR, -107.061094, 44.842295, “Sheridan”
SJN, 109.14352 , 34.424037, “St. Johns”
SLC, -111.981913, 40.85025 , “Salt Lake City”
SNY, 102.983, 41.09667, “Sidney”
SRQ, -82.554264, 27.397765, “Sarasota”
SSO, -109.263088, 32.269245,”San Simon”
TBC, -111.269588, 36.121312, “Tuba City”
TBE, -103.600056, 37.25866, “Tobe”
TCS, -107.280542, 33.2825, “Truth or Consequences”

Appendix C. Dispatcher Observation Plan

February 7-8, 2002
Delta Air Lines

http://www.rap.ucar.edu/largedrop/integrated/terminal/ice_departures.html
http://www.rap.ucar.edu/largedrop/iida
http://www.rap.ucar.edu/largedrop/iifa
http://adds.aviationweather.noaa.gov/projects/adds/icing/

Overview

We will be observing 2 dispatchers at two desks in the Delta OCC (one dispatcher at each desk). These desks have a high concentration of traffic at CVG. The observations will occur over two days.

This observational event supports a usability study using NCAR's IIDA & IIFA. The observational study will occur in situ, while the dispatchers are doing their normal work.

Significant observations will be written down on paper. As appropriate, the observations will be supported by screen captures from the dispatcher's monitors. If the dispatcher is in a high work-load condition doing the screen captures on his machine will be too disruptive, so as a fall-back we can capture the IIDA/IIFA screen the dispatcher is looking at with our laptops connected to the internet via modem. Screen captures can be accomplished by copying the screen to the clipboard using "Print Screen," then copying the results into Paint (or the like), and saving to a file. The bitmap files will be rather larger (around 4Mb or so), but can be compressed down to < 100k using gzip (this program is gnu & easily contained on a floppy).

Sequence

- Observe dispatchers without IIDA/IIFA (baseline).
- Observe dispatchers using IIDA/IIFA without training.
- Introduce and train dispatchers on IIDA/IIFA.
- Observe dispatchers using IIDA/IIFA.

Assuming that icing decisions are not being made, we will pose icing related judgment questions to the dispatchers in order to observe if/how they use IIDA/IIFA.

Observation Goals

Our primary objectives will be to find out how the dispatchers understand the state of the weather (icing in particular), how IIDA/IIFA might impact how the dispatchers understand the state of the weather, how dispatcher use their understanding of icing to make job-relevant decisions, how IIDA/IIFA might impact these job-related decisions, usability issues with respect to IIDA/IIFA, what the dispatchers like/dislike about IIDA/IIFA, and what their suggestions are for the products.

Observations

Without IIDA/IIFA

-How do icing conditions impact your decision making? I.e. for what decisions do you need information about icing? What decision are most critical? What decisions are most difficult? What decisions are most easy?

-How do you determine if there are currently icing conditions? What tools do you use? Ask dispatcher to show how they do this.

-How do you determine if there will be icing conditions? What tools do you use? Ask dispatcher to show how they do this.

-How do you keep yourself aware of icing? Ask dispatcher to show how they do this.

-Do you try to discriminate between structural (hard) ice and engine (ice)? If so, what tools do you use to do this? Ask dispatcher to show how they do this.

What do you like or dislike about the icing products you use? What other information would you like to have?

IIDA/IIFA without Intro/Training

-Show dispatcher IIDA/IIFA and ask them what they think it show them. Allow dispatcher to use the tool. Look for misunderstandings, difficulties using, etc.

-Ask dispatcher how they think they might use such a tool for their job.

-Do you know what SLDs are? What is the importance of SLDs for aircraft?

-Visible moisture?

-What do the colors mean on the maps?

Train IIDA/IIFA

IIDA/IIFA after training

General Questions

-Ask dispatcher again how they might use the product for their job. Any changes?

-Ask how he would use IIDA/IIFA, if at all, in concert with other products?

-Does the dispatcher understand the products? Is it clear that this is a likelihood value for potential icing (SLD if it is available)?

-What utility does potential icing have for them, if any? (As opposed to severity information, for example)?

-Utility of SLD? Utility of Visible Moisture? Icing/SLD/Cloud tops/bases?

- Is the SID/STAR concept useful or would another paradigm be preferable?

-Does the dispatcher view IIDA/IIFA when we don't prompt him? What other icing relevant products does he use?

-Does the dispatcher use IIDA/IIFA correctly? I.e. does the dispatcher make correct inferences based on IIDA/IIFA?

-What parts of the IIDA/IIFA tools does the dispatcher not use?

Terminal Scale Screen
-Is the range of the map appropriate?

-Is the icing potential scale (i.e. 10% bins) appropriate?

-Are the dispatchers able to discriminate between colors?

-Are the dispatchers able to understand what the pirep symbols mean?

-Are the lines representing the routings on the display useful?

-What problems does the dispatcher have navigating the tool?

-Color of text?

-Position/layout of items on display?

-Size of items on display?

-Would you to be able to select a likelihood threshold?

-Performance of tool (does it load quickly, are the any problems displaying pages)?

-Are links to other products used?

Vertical Cross Sections
-Is the range of the map appropriate?

-Is the icing potential scale (i.e. 10% bins) appropriate?

-Is the height scale appropriate?

-Are the dispatchers able to discriminate between colors?

-Are the dispatchers able to understand what the pirep symbols mean?

-Position/layout of items on display?

-Size of items on display?

-Would you to be able to select a likelihood threshold?

-Performance of tool (does it load quickly, are the any problems displaying pages)?

Horizontal Cross Sections
-Are 2000 ft. increments appropriate?

-Is the range of the map appropriate?

-Is the icing potential scale (i.e. 10% bins) appropriate?

-Are the dispatchers able to discriminate between colors?

-Are the dispatchers able to understand what the pirep symbols mean?

-Position/layout of items on display?

-Size of items on display?

-Would you to be able to select a likelihood threshold?

Icing Tops/Bases
-Is scale appropriate?

-Is the range of the map appropriate?

-Are the dispatchers able to discriminate between colors?

-Are the dispatchers able to understand what the pirep symbols mean?

-Position/layout of items on display?

-Size of items on display?

Other Products
-Show http://adds.aviationweather.noaa.gov/projects/adds/icing/

Debrief

-IIDA/IIFA likes/dislikes?

-Dispatcher suggestions?

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13. ABSTRACT ***(Maximum 200 words)***
The long-term operational concept of this research is to develop an onboard aircraft system that assesses and reports atmospheric icing conditions automatically and in a timely manner in order to improve aviation safety and the efficiency of aircraft operations via improved real-time and forecast weather products. The idea is to use current measurement capabilities on aircraft equipped with icing sensors and in-flight data communication technologies as a reporting source. Without requiring expensive avionics upgrades, aircraft data must be processed and available for downlink. Ideally, the data from multiple aircraft can then be integrated (along with other real-time and modeled data) on the ground such that aviation-centered icing hazard metrics for volumes of airspace can be assessed. As the effect of icing on different aircraft types can vary, the information should be displayed in meaningful ways such that multiple types of users can understand the information. That is, information must be presented in a manner to allow users to understand the icing conditions with respect to individual concerns and aircraft capabilities. This research provides progress toward this operational concept by: identifying an aircraft platform capable of digitally capturing, processing, and downlinking icing data; identifying the required in situ icing data processing; investigating the requirements for routing the icing data for use by weather products; developing an icing case study in order to gain insight into major air carrier needs; developing and prototyping icing display concepts based on the National Center for Atmospheric Research's existing diagnostic and forecast experimental icing products; and conducting a usability study for the prototyped icing display concepts.

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